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LEONARDO MARINHO DE OLIVEIRA

TAFONOMIA DE VERTEBRADOS E O PRIMEIRO DINOSSAURO DA FORMAÇÃO ALIANÇA, JURÁSSICO SUPERIOR DA BACIA DE JATOBÁ

Recife
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Dissertação apresentada ao Programa de Pós-Graduação em Geociências, do Centro de Tecnologia e Geociências, Universidade Federal de Pernambuco, orientada pelo Prof. Dr. Edison Vicente Oliveira e coorientada pelo Prof. Dr. Gelson Luís Fambrini, como preenchimento parcial dos requisitos para a obtenção do grau de Mestre em Geociências, área de concentração de Geologia Sedimentar e Ambiental.

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Leonardo Marinho de Oliveira

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Dedico esta dissertação a todos os cientistas, que nos últimos dois anos (2020-22) viveram tempos de negacionismo, e aos milhares de mortos pela Covid-19. Dedico também a minha eterna cantora Isabel Ferreira e ao eterno amigo Pedro Alves (*in Memorian*)

“E tudo será novamente nosso, ainda que cadeias nos pés e azorrague no dorso...
E nosso queixume será uma libertação derramada em nosso canto!
- Por isso pedimos, de joelhos pedimos: Tirem-nos tudo...
mas não nos tirem a vida, não nos levem a música!”
Noémia de Sousa, em *Súplica*.

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Aos meus pais, Maria Cristina e Gilson, pela educação proporcionada e o convívio árduo nessa pandemia. A minha irmã Luana e a minha sobrinha Luisa, meu melhor presente nesses 2 anos de vida. O mundo é teu, Lulu!

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RESUMO

A Formação Aliança, integrante do Grupo Brotas, Bacia de Jatobá, representa o primeiro pulso lacustre que ocorreu durante a fase de início de rifte nos primeiros esforços de separação do Gondwana Ocidental, durante o Neojurássico. Nesse contexto, uma importante fauna de vertebrados é encontrada em diversos estratos dessa unidade, principalmente na região de Ibimirim, Estado de Pernambuco. Os dois objetivos principais desse trabalho incluem: (1) descrever as tafofáceis de vertebrados e (2) realizar o estudo taxonômico do primeiro fóssil de dinossauro dessa formação. A tafocenose encontrada é constituída fundamentalmente por elementos ósseos desarticulados. A partir da determinação de litofácies, de classes tafonômicas e de aspectos tafonômicos intrínsecos, como representação óssea, tipos de fraturas, marcas de abrasão e coloração de dentes e ossos, foram identificadas em calcarenitos as tafofácies A e B, e em calcilutitos, a tafofácies C. O modelo integrado sugere que a gênese das tafofácies está ligada à atuação do rebaixamento do nível de água do paleolago, e os agentes de transporte e desarticulação relacionados à exposição subaérea pré-soterramento, a ação de correntes de turbidez unidirecionais em águas rasas e provável atuação de tempestades. Para os calcilutitos da Formação Aliança é registrada uma vertebra caudal do primeiro dinossauro terópode para essa unidade, que constitui o registro mais antigo de dinossauro do jurássico brasileiro. Comparado a terópodes da América do Sul e África, esse espécime se aproxima taxonomicamente de *dilophosaurídeos* do Jurássico Médio. Finalmente, esse dinossauro representa o primeiro fóssil com um amplo poder de correlação paleobiogeográfica e bioestratigráfica, reforçando à idade do Jurássico tardio paraa Formação Aliança.

PALAVRAS-CHAVE: tafofácies, vertebrados, tafonomia, paleolago Jurássico, sistema lacustre, taxonomia, *Dilophosaurus*, Gondwana.

ABSTRACT

The Aliança Formation from the Brotas Group, Jatobá Basin, represents the first lacustrine pulse that occurred during the early rift phase in the first efforts to separate Western Gondwana, during the Neo-Jurassic. In this context, an important vertebrate fauna is found in several strata of this unit, mainly in the region of Ibimirim, State of Pernambuco. The two main objectives of this work include: (1) to describe the vertebrate taphofacies and (2) to carry out a taxonomic study of the first dinosaur fóssil of this formation. The taphocenosis found is basically constituted by dissociated bone elements. From the determination of lithofacies, taphonomic classes and intrinsic taphonomic aspects, such as bone representation, types of fractures, abrasion marks and coloring of teeth and bones, taphofacies A and B were identified in calcarenites, while the taphofacies C was identified in calcilutites. The integrated model suggests that the genesis of the taphofacies is linked to lowering of the water paleolake level, and the transport and disarticulation agents related to pre-burial subaerial exposure, the action of unidirectional turbidity currents in shallow waters and, likely, action of storms. For calcilutites of the Aliança Formation, a caudal vertebra of the first theropod dinosaur is recorded for this unit, which constitutes the oldest record of dinosaur from the Brazilian Jurassic. Compared to theropods of South America and Africa, this specimen is taxonomically close to *Dilophosaurus* from the middle Jurassic. Finally, this dinosaur represents the first fossil with a broad power of paleobiogeographic and biostratigraphic correlation, reinforcing the late Jurassic age for Aliança Formation.

KEYWORDS: Taphofácies, vertebrates, taphonomy, paleolake Jurassic, lacustrine system *Dilophosaurus*, Gondwana.

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1 Introdução

1.1 Apresentação

Estudos geológicos são realizados nas bacias sedimentares do nordeste brasileiro desde o século XIX (DERBY, 1879). Dentre as bacias marginais litorâneas e as bacias interiores, destacam-se as bacias do Sistema Rifte Recôncavo-Tucano-Jatobá (**RTJ**), especialmente a Bacia de Jatobá, alvo deste estudo.

A Bacia de Jatobá apresenta em seu arcabouço estratigráfico depósitos oriundos do Paleozoico ao Cenozoico (ALMEIDA, 1967), e compõe a parte final do RTJ. Sua origem está relacionada a Depressão Afro-Brasileira (PONTE & ASMUS, 1978; KUCHLE ET AL., 2011; FAMBRINI ET AL., 2016), uma feição geomorfológica que foi preenchida por esses depósitos, cuja a gênese está ligada, em parte, à extensão crustal que fragmentou o Supercontinente Gondwana, permanecendo como um rifte abortado durante o Aptiano (COSTA et al., 2007). Os depósitos juro-cretácicos de origem continental (lacustre, fluvial e eólico) estão bem representados pelo Grupo Brotas (SANTOS et al., 1990; ROCHA & LEITE, 2001). O Grupo Brotas é composto pela Formação Aliança e Formação Sergi, e consiste na sequência tectono-sedimentar de início de rifte. Essa divisão tecno-sedimentar foi proposta por Fambrini et al. (2010, 2011) para a Bacia do Araripe, e adotada e subdivida para a Bacia de Jatobá por Guzmán-González et al. (2015a) e Fambrini et al. (2016, 2019).

O objeto desta dissertação, a Formação Aliança, constitui um pacote sedimentar que tem despertado atenção nos últimos anos dada a presença de um interessante conjunto de fósseis do final do Jurássico. Esta Formação ainda carece de um melhor entendimento no contexto estratigráfico e sedimentológico, bem como taxonômico e tafonômico.

Os estudos de micro- e macropaleontologia nas unidades que compõe a fase de Início de Rifte ainda são raros (SILVA, 2012; SOUZA et al., 2012; GUZMÁN-GONZÁLEZ et al. 2016, 2019), principalmente na Formação Aliança. É sabido que a carência na caracterização paleontológica pode, por vezes, acarretar graves problemas de interpretação estratigráfica, principalmente na correlação com ambientes sedimentares similares de outras bacias juro-cretáceas. Embora a Formação Aliança constitua uma unidade relativamente bem mapeada e caracterizada litologicamente, os pacotes aflorantes na bacia envolvida neste trabalho tem recebido pouca atenção no que consiste ao detalhamento faciológico e de contatos, bem como de identificação de tafofácies e aporte de novos fósseis de vertebrados.

A idade da Formação Aliança tem sido interpretada como Jurássico Superior, pórem estudos recentes de litologias semelhantes com conteúdo fóssil correlato, aflorantes na Bacia de Lima Campos (PINHEIRO et al., 2011), no Ceará, tem sido datado como Cretáceo Inferior. Paralelo a isto, datações radiométricas da Formação Alianaça na Bacia do Recôncavo têm apontado datas indicando o final do Triássico a Jurássico Médio (SILVA et al. 2012). Essa problemática envolvendo a Formação Aliança e outras unidades de bacias interiores levanta um questionamento sobre a idade dessa unidade, tradicionalmente vinculada ao Andar Dom João, juntamente com a Formação Sergi (VIANNA, 1966; VIANNA ET AL., 1971), Biozona RT-001 (Oxfordiano/Kimmeridgiano - Tithoniano) do Neojurássico, com a fase de Início de Rifte nas bacias interiores do Nordeste brasileiro (COIMBRA ET AL., 2002; FAMBRINI ET AL., 2011).

Este estudo visa contribuir com novos dados, informações e interpretações a respeito da geologia e paleontologia da Formação Aliança, aportando novos dados e discussões sobre a sedimentação da fase de Início de Rifte que ocorreu nas bacias do Gondwana Ocidental durante o Neojurássico.

1.2 Objetivos

1.2.1 Objetivos gerais

O objetivo principal desse trabalho é caracterizar a porção lacustre da fase de Início de Rifte da bacia de Jatobá utilizando estratigrafia, estudo de fácies sedimentares e tafofácies, e contribuir para o conhecimento paleozoológico e paleogeográfico do Jurássico continental do Nordeste brasileiro.

1.2.2 Objetivos específicos

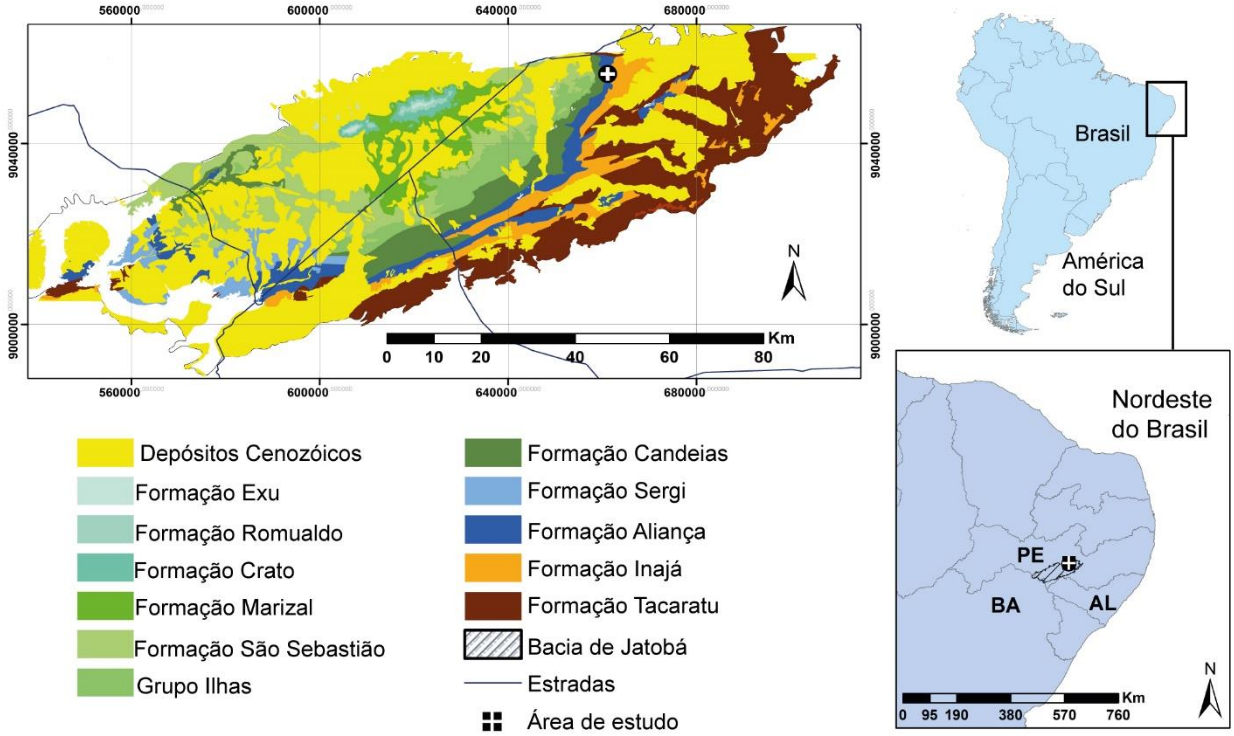
- Elaborar seções estratigráficas detalhando as fácies sedimentares da formação, realizando um estudo sistemático das estruturas sedimentares, sistemas deposicionais, e paleoambiental da Formação Aliança.
- Identificar as tafofácies de vertebrados visando a elaboração de um modelo tafonômico;
- Descrever e identificar taxonomicamente pela primeira vez para a Formação Aliança um fóssil de um dinossauro Theropoda, comparando com ocorrências em unidades neojurássicas do Gondwana Ocidental.

1.3 Localização da área de estudo

A área de estudo situa-se próxima as localidades de Macambira e Frutuoso, no município de Ibimirim, distrito de Campos (Fig. 1), na região central do estado de Pernambuco.

A bacia de Jatobá ocorre como uma faixa orientada NE-SW com uma área de, aproximadamente, 5.600 km² no sudoeste do estado de Pernambuco, no nordeste brasileiro. Estudos mais específicos na Bacia de Jatobá começam a ser realizados na segunda metade do século XX, impulsionados pelas descobertas de Petróleo na Bacia do Recôncavo. Destaca-se o trabalho de Viana *et al.* (1971), e nos últimos anos os trabalhos de Peraro (1995), Guzmán-González et al. (2015a), Fambrini et al. (2016, 2019) e Neumann *et al.* (2009, 2010, 2013, 2014 e 2017) detalharam com mais acurácia o arcabouço litológico da bacia (Figura 1).

Figura 1 – Mapa geológico da Bacia de Jatobá e localização da área de estudo. Fonte: O autor.



2 Referencial Teórico

2.1 Bacia Sedimentar de Jatobá

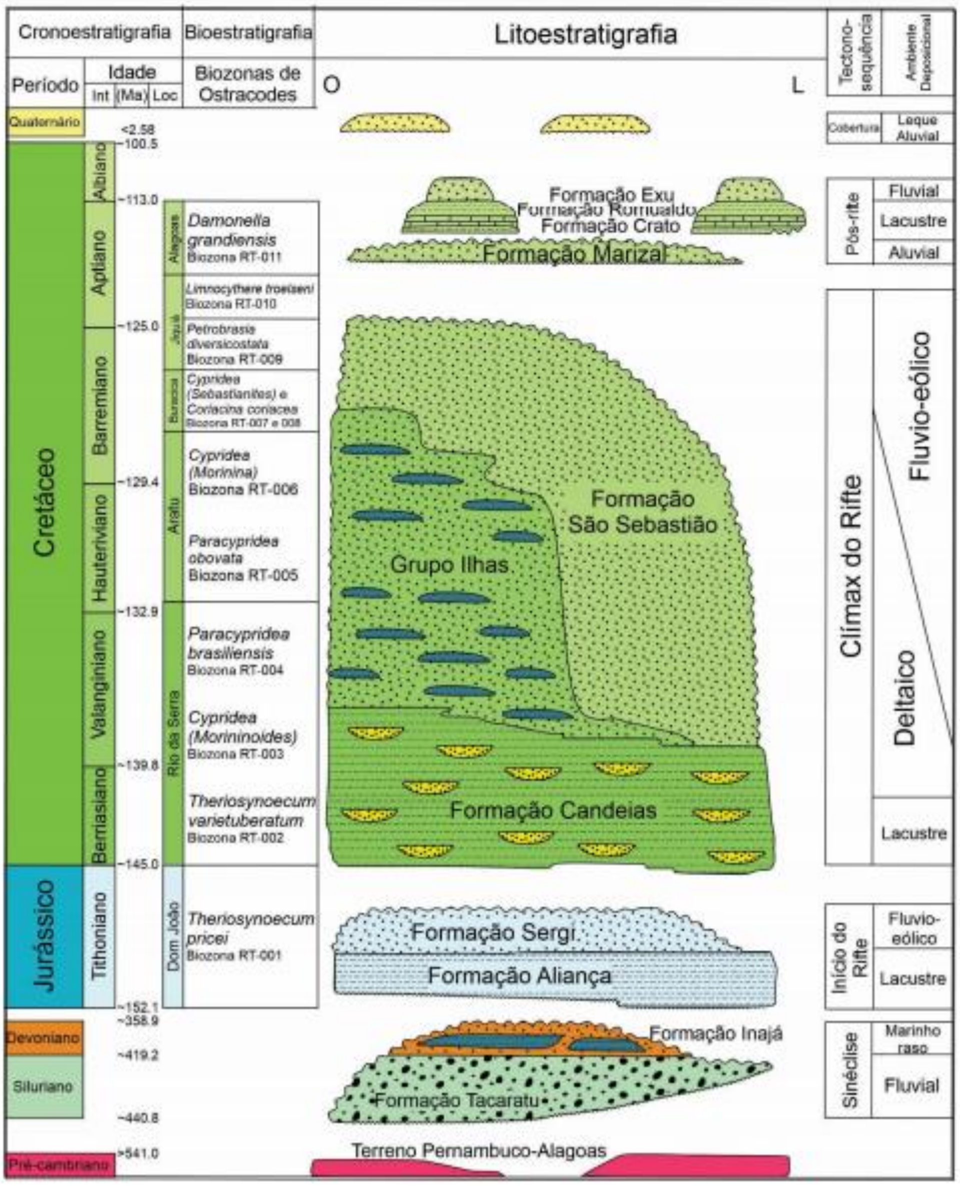
A Bacia sedimentar de Jatobá é integrante do sistema de bacias do tipo rifte abortado **RTJ** e tem sua origem ligada aos estágios iniciais de formação do Oceano Atlântico Sul, como um dos braços de ruptura que foram abortados durante a abertura do oceano (MAGNAVITA & CUPERTINO, 1987; MAGNAVITA ET AL., 1994, 2002). A orientação do **RTJ**, em essência, é N-S, mudando seu caráter na Bacia de Jatobá, onde os registros sedimentares estão orientados **ENE-WSW** por influência de reativações na Zona de Cisalhamento Pernambuco (**ZCPE**) no Eocretáceo e heterogeneidade do embasamento, constituído nessa porção pelo Terreno Pernambuco-Alagoas, no Domínio Sul da Provincia Geotectônica da Borborema **(**PERARO, 1995; SILVA-FILHO ET AL., 2013; BRITO NEVES E SILVA-FILHO, 2018).

A bacia é limitada ao norte pela Falha de Ibimirim, uma dentre o conjunto de falhas que caracterizam o **ZCPE**. Esta falha condicionou o *Graben* de Ibimirim, onde estima-se uma coluna sedimentar de 3.000m de profundidade e uma extensão de 360 Km² em área (COSTA ET AL., 2007). O empilhamento tectono-sedimentar da bacia apresenta diversas sequências distribuídas ao longo dos eventos geológicos (Figura 2) e foi subdividido por Gúzman et al., (2015) e Fambrini et al., (2016, 2019), em: 1) Fase Sinéclise (Grupo Jatobá), composta pelas formações Tacaratu e Inajá; 2) Fase de Início de Rifte (Grupo Brotas), formações Aliança e Sergi; 3) Fase de Clímax de Rifte, com a formação Candeias, Grupo Ilhas, Formação São Sebastião; 4) Fase Pós-Rifte, que contém a formação Marizal, Grupo Santana e Formação Exu.

2.2 A Formação Aliança

A Formação Aliança fazia parte da antiga Formação Brotas, reconhecida inicialmente por Shearer & Barnes (1942, 1949 apud Viana et al. 1971), e elevada a grupo pelo "Estudo da Bacia" realizado pela Petrobrás (1958, segundo Viana et al. 1971). Constituindo a primeira formação integrante da denominada Depressão Afro-Brasileira (Ponte e Asmus, 1978; Ponte, 1992; Ponte e Ponte Filho, 1996a e 1996b), a Formação Aliança marca o registro sedimentar do Neojurássico no início da fragmentação do Supercontinente Gondwana. Ponte (1994) reconhece a presença de correlatos a essa formação tanto na Bacia do Jatobá nas bacias Sergipe-Alagoas e do Araripe.

Figura 2 – Carta Estratigráfica da Bacia de Jatobá com base em Moura & Praça (1985), Moura (1988), Caixeta et al. (1994), Costa et al. (2007), Neumann et al. (2009, 2010), Rocha (2011), Guzmán et al. (2015), Nascimento et al. (2017) e Mendes et al. (2020).



A Formação Aliança, denominada por trabalhos antigos como Folhelho Aliança, é a unidade basal do Grupo Brotas e subdividida por Viana et al. (1971) em três membros: Afligidos, Boipeba e Capianga. O Membro Afligidos, de idade permiana, veio a ser elevado a formação posteriormente por Aguiar e Mato (1990) para a Bacia do Recôncavo. A espessura da formação na Bacia do Jatobá envolve cerca de 150 m (Rocha e Amaral, 2007) de uma sucessão heterolítica composta por folhelhos, argilitos e siltitos roxos a verdes, dominantemente e, subordinadamente, arenitos, calcarenitos esbranquiçados a marrom claro abundantemente fossilíferos e evaporitos.

Vianna et al., (1971) caracterizaram o Grupo Brota como andar local Dom João, realizando um mapeamento de biozonas com ostracodes não marinhos. A Biozona RT 001 é caracterizada por um biozona de abundancia do táxon *Theriosynoecum pricei*, ainda se caracteriza essa biozona por uma associação de outros taxa, como: *T. pricei*, *T. quadrinodosum*, *Reconcavona jatobaensis* e *Alicenula spp.* (Arai et al., 2001; Coimbra et al., 2002; Poropat e Colin, 2012; Guzmán-Gonzáles et al., 2016, 2020). Além da abundancia de ostracodes, é notável a presença de conchostráceos da espécie *Cyzicus brauni*, e fósseis de vertebrados dos gêneros *Lepidotes*, *Planohybodus* e *Mawsonia* (Silva et al., 2011).

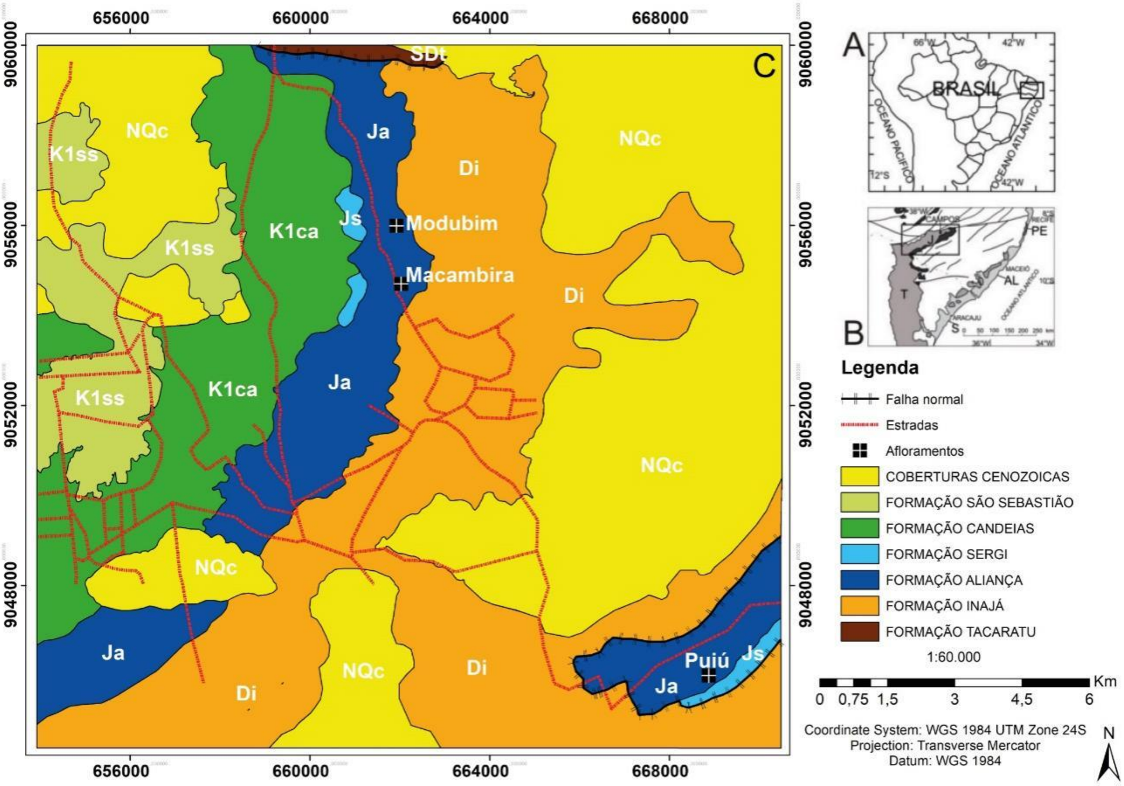
O sistema deposicional corresponde a um ambiente lacustrino com significativo *input* fluvial combinado a altas taxas de evaporação com deposição de evaporitos. Esta formação é correlacionada à Formação Bananeiras na Bacia Sergipe-Alagoas, e à Formação Brejo Santo na Bacia do Araripe (Braun 1966, Schaller 1969, Ponte 1994, Valença et al. 2003, Costa et al. 2007, Assine 2007, Campos Neto et al. 2007, Fambrini et al. 2011, 2013a, Scherer et al. 2014). Na Bacia do Gabão, na África, é correlacionada aos lamitos do topo da Formação M'Vone (Davison 1999, Mounguengui et al. 2008, Teisserenc e Villemin 1990).

3 Material e Método

3.1 Descrição litológica, perfis estratigráficos e caracterização faciológica

Os afloramentos estudados da Formação Aliança na Bacia do Jatobá ocorrem no município de Ibimirim/PE, perto da localidade de Frutuoso (Figura 3), e são denominados como Modubim, Macambira e Puiú. Nessa região é possível encontrar o contato sotaposto com a Formação Inajá e o contato sobreposto com a Formação Sergi, assim como se aproxima na região do baixo de Frutuoso, onde a formação possui maior espessura.

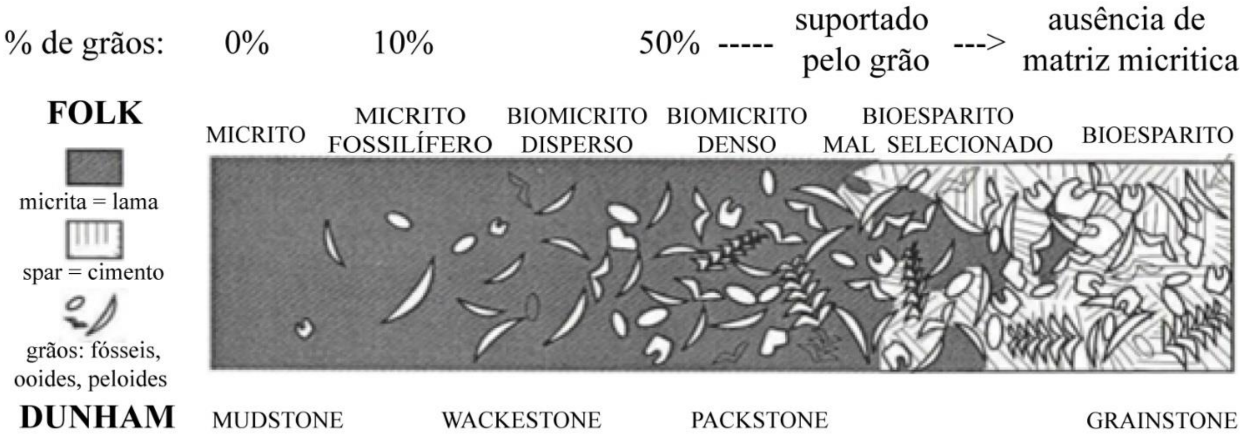
Figura 3 – A) localização do estado de Pernambuco; B) contexto tectônico da Bacia de Jatobá; C) mapa geológico do entorno das localidades de Frutuoso e Trocado. Fonte: O autor.



Foram realizadas quatro etapas de campo, totalizando 16 dias, entre os anos de 2018 a 2021 para estrudos de afloramento, analises faciológicas e coleta de amostras de rochas, que foram catalogadas e classificadas. As amostras de rochas areniticas foram classificadas segundo Dott (1964). Para as amostras de rochas carbonaticas, contudo, existem diferentes classificações na literatura. Para Gabrau (1904), que se baseia no tamanho médio dos grãos, as amostras são subdivididas em calcilutitos, calcarenitos e calciruditos, por ordem crescente de granulação, respectivamente. Esta classificação é importante, porém não excludente, para trabalhos de mapeamento em relação a textura da rocha. Outras classificações investigam o arcabouço petrográfico da amostra carbonática. Folk (1962) baseia sua classificação na proporção de grãos alobioquímicos, matriz micritica e cimento esparítico. Enquanto Dunham (1962) utiliza a textura da rocha unida organicamente durante a deposição Figura (4).

A interpretação de fácies sedimentares e sistemas deposicionais foi baseada em Anadon et al. (1991), Miall (1977, 1978, 1996, 2000, 2014), Schanley e McCabe (1994), Talbot e Allen (1996), Tucker & Wright (1990) e Platt e Wright (1991) A construção de perfis estratigráficos foi baseada em Selley (2000). A integração de dados geológicos, paleontológicos e estratigráficos foram compilados, modelados e agrupados nos *softwares Corel Draw* e *ArcMAP View*.

Figura 4 – Classificação de Dunham (1962) vs. Classificação de Folk (1062) e modificado por Embry and Klovan (1971).



3.2 Análise paleontológica, tafonomia e tipificação de tafofácies

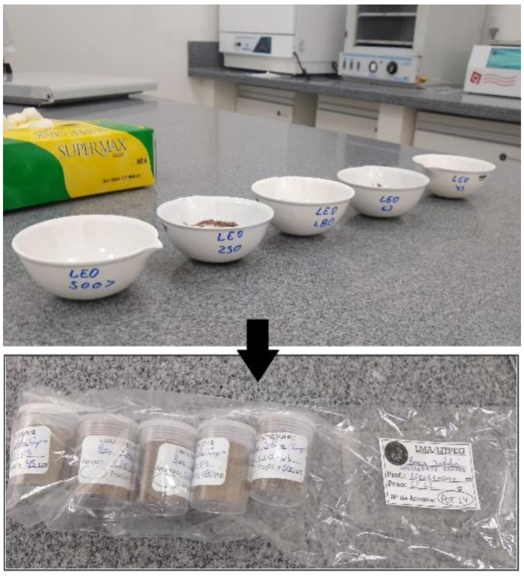
Os dados paleontológicos seguiram coletas seletivas de macro- e microfósseis presentes na formação. A etapa de coleta de fósseis consistiu na procura de vestígios de restos fósseis em campo, através de uma prospeção minuciosa de afloramentos. Foi também coletado amostras para lavagem e peneiramento de sedimentos visando pequenos vertebrados, seguindo-se os itens recomendados por Clemens (1965), Grady (1979), Cifelli (1996) e Cifelli et al. (1996). As etapas envolvidas tiveram início com a seleção de fácies favoráveis à preservação de restos de pequenos vertebrados, os quais são geralmente representados por dentes isolados, ossos pós-cranianos, etc.

Depois de coletado, as amostras de rocha foram submetidas a um processo de preparação química com Ácido Acético ou similares visando à desagregação dos grãos. Após esta etapa, o material deve ser secado em estufa. Nos macrofósseis de maiores dimensões foram realizados a preparação mecânica com o auxílio de martelo, talhadeira e microretífica Dremil.

Os macrofósseis observados nessas amostras foram visualizados com o auxílio do estereomicroscópio Zeiss Esteodiscovery V8 e fotografados pela câmera acoplada Axiocam MXC. As fotomicrografias foram obtidas pelo software AxioVision Release 4.8. As fotografias destes foram realizadas com a câmera Nikon Coolpix P520. Todo o processo metodológico foi realizado na estruturada do PALEOLAB-DGEO-UFPE, que conta com laboratório de preparação de fósseis e sala de Microscopia.

Para as amostras de microfósseis de valor bioestratigráfico, a preparação seguiu a metodologia de preparação de microfósseis calcários. O material foi desagregado manualmente até se obter 62g de amostra e colocado em repouso em um becker com água durante o período de 24 horas. Como a amostra é extremamente abundante em microfósseis, não foi necessário utilizar o ataque com peróxido de hidrogênio (H2O2). Em seguida a amostra foi lavada e separada utilizando cinco empilhamentos de peneiras, em sequência descendente: 500, 250, 180, 63 e 45µ (Figura 5). Após a separação, as amostras foram secadas em estufa e separadas para análise em microscópio estereoscópico. Toda a metodologia dessa etapa foi realizada no Laboratório de Micropaleontologia Aplicada (LMA-UFPE), integrante do Instituto de Pesquisa em Petróleo e Energia (LITPEG - PETROBRAS).

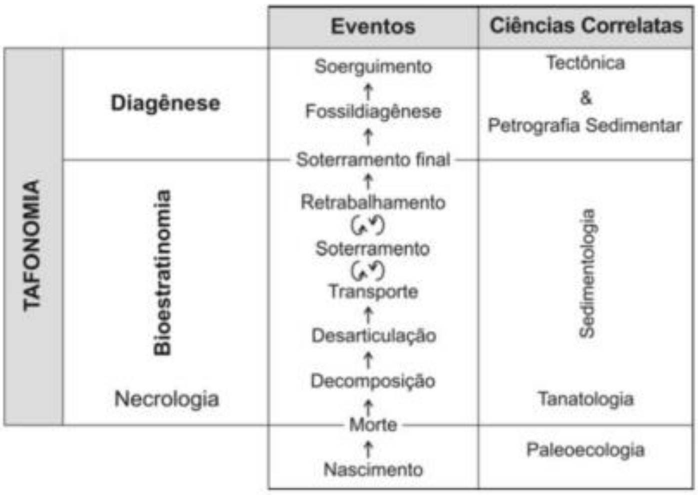
Figura 5 – Preparação e separação da amostra para triagem. Fonte: O Autor.



Os estudos tafonômicos seguiram diversos autores. A tafonomia foi um termo cunhado pelo paleontólogo russo Ivan Efremov em 1940. Contudo, estudos prévios a essa data já estudavam os preceitos da ciência que investiga a formação e preservação dos fósseis. Segundo Behrensmeyer & Kidwell (1985), tafonomia é a ciência que estuda o processo de preservação dos fósseis e a qualidade do registro fossilífero dentro do arcabouço geológico.

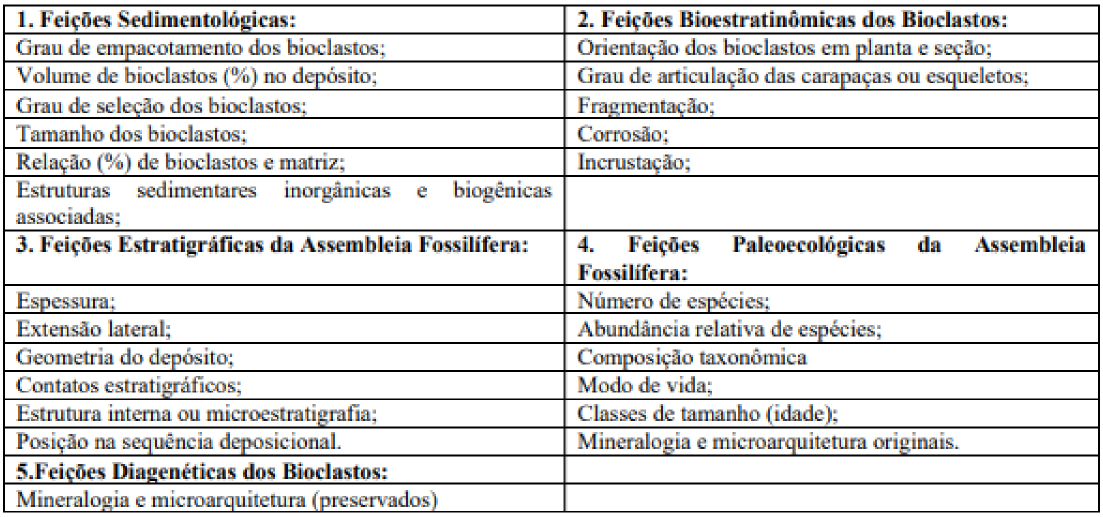
Holz & Simões (2002) e Simões et al. (2010), dividem a tafonomia em dois campos, A bioestratinomia e a fossildiagênese (Figura 6). A bioestratinomia é a primeira etapa de preservação do registro fóssil, passando pelas fases de decomposição, desarticulação, transporte, soterramento, retrabalhamento e soterramento final. A fossildiagenese engloba as mudanças físico-químicas que ocorrem no registro fóssil após o soterramento final.

Figura 6 – Processos tafonômicos por Holz & Simões (2002).



Segundo (Kidwell, 1991), Simões et al. (2010) e Prado (2015), para análise do arcabouço tafonômico é necessário a descrição de feições tafonômicas envolvendo os campos da sedimentologia, paleoecologia, estratigrafia, bioestratinomia e diagênese (Figura 7).

Figura 7 – Feições tafonômicas adaptado de Prado (2015).



1. Feições Sedimentológicas:	**2. Feições Bioestratinômicas dos Bioclastos:**
Grau de empacotamento dos bioclastos;	Orientação dos bioclastos em planta e seção;
Volume de bioclastos (%) no depósito;	Grau de articulação das carapaças ou esqueletos;
Grau de seleção dos bioclastos;	Fragmentação;
Tamanho dos bioclastos;	Corrosão;
Relação (%) de bioclastos e matriz;	Incrustação;
Estruturas sedimentares inorgânicas e biogênicas associadas;	
3. Feições Estratigráficas da Assembleia Fossilífera:	**4. Feições Paleoecológicas da Assembleia Fossilífera:**
Espessura;	Número de espécies;
Extensão lateral;	Abundância relativa de espécies;
Geometria do depósito;	Composição taxonômica
Contatos estratigráficos;	Modo de vida;
Estrutura interna ou microestratigrafia;	Classes de tamanho (idade);
Posição na sequência deposicional.	Mineralogia e microarquitetura originais.
5.Feições Diagenéticas dos Bioclastos:	
Mineralogia e microarquitetura (preservados)	

O agrupamento de feições tafonômicas está para a interpretação de tafofácies, assim como a trama litológica está para interpretação de fácies litológicas. É preciso analisar o conjunto de feições para chegar em um denominador comum para reconstrução de tafofácies e determinar classes tafonômicas que tenham feições em comum para o mesmo depósito sedimentar/fossilífero. A amarração das classes tafonômicas com o arcabouço litológico (litofáceis) gera a tipificação das tafofácies. Essa metodologia é amplamente usada para vertebrados e representa o estágio da geração tafonômica e da tafocenose dos restos esqueletais (Dodson, 1971; Gradzinsky, 1970; Holz e Barberena, 1994; Soares, 2003).

4 Resultados

Os resultados desta dissertação estão estruturados na forma de artigos científicos em períodicos indexados na área de Geociências da Coordernação de Aperfeiçoamente Pessoal (CAPES), em conformidade com o regimento do Programa de Pós-Graduação de Geociências (PPGEOC/UFPE). Encontram-se organizados em dois manuscritos. O primeiro artigo denomina-se “Vertebrate taphonomy and taphofacies of the Capianga Member, Aliança Formation (Jurassic), Jatobá Basin, Brazil”, trata da análise de feições, classes tafonômicas e descrição das tafofácies. O segundo artigo denomina-se: “The first dinosaur from the Late Jurassic Aliança Formation of northeastern Brazil, west Gondwana: a basal Neotheropoda and its paleobiogeographical significance”. Relata a ocorrência do primeiro dinossauro terópode da Formação Aliança, conjuntamente com a analise sistemática paleontológica, comparações anatômicas e discussão a respeito da paleobiogeografia do Gondwana Ocidental. Ambos foram submetidos e publicados no *Journal of South American Earth Sciences*.

ARTIGO 1

VERTEBRATE TAPHONOMY AND TAPHOFACIES OF THE CAPIANGA MEMBER, ALIANÇA FORMATION (JURASSIC), JATOBÁ BASIN, BRAZIL

LEONARDO MARINHO DE OLIVEIRA

HERMÍNIO ISMANEL DE ARAÚJO JÚNIOR

EDISON VICENTE OLIVEIRA

GELSON LUIS FAMBRINI

VERTEBRATE TAPHONOMY AND TAPHOFACIES OF THE CAPIANGA MEMBER, ALIANÇA FORMATION (JURASSIC), JATOBÁ BASIN, BRAZIL

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Abstract:

In addition to the study of sedimentary facies, the reconstruction of paleoenvironments depends on a detailed understanding of the taphonomy of a fossil accumulation. The Capianga Member of the Aliança Formation (Middle to Late Jurassic of the Jatobá Basin, northeastern Brazil) reveals vertebrate fossil accumulations composed predominantly of disarticulated bone and osteoderms, scales, spines and isolated teeth from a lacustrine paleoenvironment. However, the taphonomic history of the accumulation has not yet been studied extensively. The present work aims to interpret taphonomic facies based on lithological data and the systematic collection of fossils from the Capianga Member of the Aliança Formation, located in the northeastern portion of the Jatobá Basin, mainly in the municipality of Ibimirim. Six lithofacies were identified: Fm – massive claystones, Fl – Shale laminated Lt – calcilutites, Lc – calcarenites, Gf – fibrous gypsum and Scl – calciferous sandstones. Two primary taphonomic classes were recognized, consisting essentially of disarticulated elements, including (1) incomplete, semi-complete, or rarely complete bioclasts (such as osteoderms and fish scales) and (2) small-sized, occasionally complete bioclasts (osteoderms and scales) that sometimes compose bonebeds. According to the vertebrate taphonomy characteristics, three taphofacies were identified, with the Taphofacies A and B occurring in calcarenites and the Taphofacies C in calcilutites. The interpretation of these taphofacies reveals a multi-episodic history of the lacustrine environment. The integrated model suggests that the genesis of the identified taphofacies is linked to the action of lowering the water level of the paleolake, as well as the agents responsible for transport and disarticulation. These agents are related to pre-burial sub-aerial exposure, the action of unidirectional turbidity currents in shallow waters, and the likely influence of storms.

Keywords: bonebeds; disarticulation; carbonates; storms; lake.

1. Introduction

Taphonomic studies on Mesozoic faunas of Brazilian basins, particularly those of the Jurassic period, are scarce, especially that investigate the causes of death and the preservation of vertebrate fauna. In this context, the Capianga Member of the Aliança Formation (Jurassic of Jatobá Basin) presents a singular vertebrate fauna, composed mainly of highly fragmented bone and dermal elements, scales, spines and isolated teeth, restricted to disjointed remains. This vertebrate-bearing fossil record is extremely important, as it is located in a poorly sampled paleogeographic sector of Western Gondwana (Goodwin et al. 2019). Previous research on the Capianga Member has predominantly focused on paleontological systematics (Silva 2012; Carvalho et al. 2021) and the regional tectonostratigraphic evolution of the Jatobá Basin (Braun 1966; Schaller 1969; Ponte 1994; Valença et al. 2003; Costa et al. 2007; Campos Neto et al. 2007; Neumann et al. 2010, 2013, 2017; Neumann and Rocha, 2014; Guzmán-González et al., 2015, 2016, 2020; Fambrini et al. 2016, 2019, 2023a, b), with no research on the taphonomical accumulation.

Regarding its vertebrate fauna, Silva (2012) conducted a study on paleoenvironmental reconstruction utilizing systematic and paleoecological aspects of paleovertebrates from the Capianga Member. That author described cranial bones of actinistian fish from *Mawsonia*, dental plates of dipnoi fish *Ceratodus*, scales and bones of “*Lepidotes”*, teeth and fin spines of the hibodontiform shark aff. *Planohybodus* sp., and teeth and osteoderms of Mesoeucrocodylia indet. Recently, Carvalho et al. (2021) described new skeletal remains of crocodylomorphs, and De Oliveira et al. (2022) provided the first description of a basal Theropoda from the Capianga Member. The reworked fossil assemblage of the Capianga Member occurs within the calcarenites and, to a lesser extent, within the calcilutites (De Oliveira et al. 2022), but there are no studies recognizing its main taphonomic features to date. This raises an important question regarding the expected preservation mode for typical lacustrine environments (i.e. good preservation and presence of articulated elements).

This study aims to interpret taphofacies based on sedimentological data and the taphonomic classes identified in the Capianga Member of the Aliança Formation, located in the northeastern portion of the Jatobá Basin, northeastern Brazil. Our main results and conclusions shed light on the depositional and preservation aspects of vertebrates in lacustrine environments as well as improve the knowledge on the paleoenvironment during the Jurassic of northeastern South America.

2. Geologic setting

The Aliança Formation, together with the overlying Sergi Formation, is part of the Brotas Group, first referenced by Shearer and Barnes (1942, 1949) and formally recognized by Viana et al. (1971). This group represents the earliest sedimentary occurrence in the basin, recording the initial efforts of separation of the Gondwana Supercontinent. The Gondwana breakup resulted in three rift segments, two of which formed the Atlantic Ocean, while a third was aborted, giving rise to the aulacogen basin system of the Recôncavo-Tucano-Jatobá Rift System (RTJ) (Magnavita and Cupertino 1987; Magnavita et al. 1994, 2012). The Recôncavo and Tucano basins display a N-S orientation, whereas the Jatobá Basin exhibits an ENE-WSW orientation (Peraro 1995), linked to pre-existing structures of the crystalline basement and the Pernambuco Shear Zone (ZCPE).

The Early Rift phase (sensu Fambrini et al. 2010, 2011, 2013; Kuchle et al. 2011; Guzmán et al. 2015a, 2015b, 2016; Fambrini et al. 2016, 2019a, 2023a, 2023b) characterizes the initial movements of fragmentation and separation of the Gondwana Supercontinent. During this phase, fluvio-eolian-lacustrine deposits are represented in the Aliança and Sergi formations within the RTJ. The Aliança Formation portrays lacustrine deposits influenced by fluvial activity during the tectonostratigraphic Early Rift phase of the Jatobá Basin (Fig. 1).

In formal lithostratigraphic terms, Aliança Formation is subdivided into the Boipeba and Capianga members, with the latter being the sole unit occurring in the eastern portion of the basin. The Capianga Member exhibits a thickness of 150 meters, representing the maximum flooding surface of the initial lacustrine pulse within the basin (Rocha and Amaral 2007; Kuchle et al. 2011; Rocha 2011). Kuchle et al. (2011) identified the facies assemblage studied here as part of the final portion of the first fluvio-lacustrine sequence deposited following the onset of the fragmentation of Western Gondwana. In South America and Africa, correlates of the Aliança Formation are identified in the Sergipe-Alagoas, Araripe and Gabon basins: Bananeiras Formation (Schaller 1969; Davison 1999; Campos Neto et al. 2007; Kifumbi et al. 2017; Castro et al. 2019), Brejo Santo Formation (Braun 1966; Ponte 1994; Valença et al. 2003; Assine 2007; Fambrini et al. 2011, 2013; Scherer et al. 2014) and M'Vone Formation (Teisserenc and Villemin 1990; Mounguengui et al. 2002, 2008), respectively.

The paleogeographic context of this formation suggests an extensive area characterized by an endorheic drainage basin, identified as the "Afro-Brazilian Depression" (Cesero and Ponte 1972; Ponte and Asmus 1978; Da Rosa and Garcia 2000; Fambrini et al. 2010, 2011; Kuchle et al. 2011; Fambrini et al. 2017, 2019a; Castro et al. 2019; Fambrini et al. 2023a, 2023b, 2023c), where drainage systems exhibited a circumscribed pattern, with river discharge unconnected to a marine environment (Kuchle et al. 2011), fostering the development of a lacustrine depositional system.

In this context, several authors have studied the Jurassic fauna inhabiting the central region of Western Gondwana. Among these, the study of biozonation using ostracods conducted by Viana (1966) and Viana et al. (1971) stands out, where the Brotas Group was placed in the local Dom João stage (Biozone RT-001) of Tithonian age, characterized by the abundance of taxa such as *Theriosynoecum*, *Reconcavona*, and *Alicenula*, all representing freshwater ostracods (Guzmán-González et al. 2016, 2020). Associated with the ostracod fauna, conchostracans of the genus *Cyzicus* have been described (Cardoso 1966; Carvalho 1993), further indicating the continental nature of these deposits. De Oliveira et al. (2022) described the first dinosaur Theropoda for the Capianga Member, pointing out the affinity of the described vertebra with basal neotheropods of the Dilophosauridae clade also represented in formations from the early to mid-Jurassic (Madsen 1976; Coria and Salgado 1998; Marsh and Rowe 2020) of North America, South Africa, and Antarctica. Consequently, De Oliveira et al. (2022) proposed a Middle to Late Jurassic age for the Capianga Member.

3. Material and methods

The specimens studied originate from two paleontological sites: Mudobim – MB (661780 E; 9056051 N) and Macambira – MC (661107 E; 9053926 N) (Fig. 1E), both part of the Campos locality in the municipality of Ibimirim, state of Pernambuco. Despite the distance between the paleontological sites of 500 meters approximately, both are stratigraphically correlated. The samples are cataloged and stored in the Paleontology Laboratory (Paleolab) of the Department of Geology at the Federal University of Pernambuco (DGEO-UFPE).

The analysis of sedimentary facies followed studies on lacustrine environments (e.g. Anadón et al. 1991; Talbot and Allen 1996; Malka et al. 1999; Bohacs et al. 2000; Bordy and Catuneanu 2001; Jones et al. 2001; Cavinato et al. 2002; Sáez and Cabrera 2002; Bohacs et al. 2003; Scherer et al. 2007) as well as fluvial environments (e.g. Miall 1978, 1996, 2006a, 2014). Analyses of factors such as lithology, sedimentary structures, body geometries, paleocurrent patterns, and associated fossils were necessary for lithofacies characterization and interpretation of the depositional system.

To determine the taphonomic aspects of the Capianga Member, various macro- and microvertebrates were collected over years of research by us, expanding the fossil assemblage of the formation. The gathering was carried out using hammers, chisels and brushes, respecting the taphonomic aspects of the occurrences. This study was concentrated in 125 specimens from the calcarenites and calcilutites. Of these, 75 were taxonomically identified, while 50 are unidentified bone fragments, both taxonomical and anatomical. All the elements collected are small and fragmented, an intrinsic characteristic of the Capianga member fossils.

The collected fossils were analyzed using a Zeiss Stereodiscovery V8 stereomicroscope and photographed using an attached Axiocam MXC camera. Photomicrographs were obtained using AxioVision Release 4.8 software. For macrofossils embedded in calcarenites, mechanical preparation was carried out using a hammer, chisel, and Dremil microgrinder. Photographs were taken with a Canon TS3 camera.

Araújo-Júnior et al. (2012) emphasize that the representation of bones in the fossil assemblage reveals important information about taphonomic processes, such as the accumulation of skeletal remains by physical and biological agents (Behrensmeyer 1991; Lyman 1994) and the intensity of transport agents (Voorhies 1969; Behrensmeyer 1975). The convergence of these taphonomic factors within a sedimentary deposit supports paleoenvironmental interpretation (Cladera et al. 2004).

We utilized the three groups of transportability by Voorhies (1969). Voorhies (1969) conducted a systematic study on transport intensity, identifying categories as autochthonous, parautochthonous, and allochthonous for recent sheep and coyote bones found in fluvial channels. In addition, three groups of transportability were presented. Voorhies' groups have limited results when the fossil assemblage comprises large vertebrates like dinosaurs and Quaternary megafauna mammals (Myers and Storrs 2007; Araújo-Júnior et al. 2012), as they disregard factors such as density, shape, and weight, behaving as sedimentary particles during fluvial transport (Behrensmeyer 1975). In this context, results are more reliable when applying the Fluvial Transport Index (FTI) coined by Frison and Todd (1986), based on experiments with recent Indian elephant bones. As the studied fossil assemblage contains a variety of sizes, from small fish bones to medium to large vertebrate bones such as mawsoniids, coelacanths, and sauropods, both Voorhies' groups and FTI were applied to their respective groups. For the analysis of transportability in large vertebrates, it is essential to correlate the FTI with the

Number of Identifiable Skeletal Parts (NISP). For this correlation, the Paleontological Statistics software (PAST; Hammer et al. 2001) was used.

To qualify, quantify, and describe the taphonomic history of the fossil, Behrensmeyer's (1978) six stages of weathering were applied. These stages highlight the presence or absence of soft parts, the number of fractures, tooth and bone coloration, and the presence and intensity of abrasion and dissection marks. To improve the presentation of the data, the Behrensmeyer stages will be described together with the taphofacies analysis. Analyzing the intensity of abrasion marks is an important tool for inferring the hydraulic transportation. These attributes are produced during the biostratinomic phase, where the fossil material undergoes traction during transportation, colliding with external physical agents such as water, sediments, and other fossils (Shipman 1981; Uzunidis et al. 2021).

Regarding skeletal disarticulation, several studies establish taphonomic classes based on the degree of skeletal articulation, characterizing completely articulated, partially articulated, or completely disarticulated skeletons (Gradzinsky 1970; Dodson 1971; Holz and Barberena 1994). As the majority of fossils in this study lack articulation, the taphonomic classification of skeletal material was limited to types of fractures, abrasion marks, weathering degree, disarticulation, and transportability groups (Voorhies 1969; Behrensmeyer 1978, 1991; Smith 1993).

4. Sedimentary facies

For taphonomic characterization, it was essential to relate the preservation of the fossils in each lithofacies to the genetic process of the facies in question. Based on the studied outcrops and the sedimentary log raised from Macambira and Modubim outcrops (Fig. 2), six lithofacies were characterized for the Capianga Member, described in Table 1 and represented in Figure 4. Thus, the following lithofacies were identified: massive mudstone facies (Fm); Laminated shales facies (Fl); calcilutite facies (Lt); fibrous gypsum facies (Gf); calcarenite facies (Lc); laminated calcareous sandstone facies (Scl).

5. Results

5.1 Facies Associations

The interpretation of depositional processes and lithofacies indicates that these seven lithofacies of the Aliança Formation were deposited in two major lacustrine subenvironments, which are described below.

5.1.1 Wave-dominated Coastal Lake Environment (WCLE)

A coastal lacustrine environment dominated by waves is represented by the lake margin facies association, consisting of carbonate banks, cream-colored calcarenites beds together with greenish calcilutites (Fig. 4A), and rare occurrences of gypsum in synaeresis cracks (Fig. 3D), along with laminated calcareous sandstones and marl layers. Sedimentary structures found include cross-bedding, low-angle cross-bedding, shrinkage cracks, and abundant ripple marks. Petrography reveals that the carbonate banks are primarily composed of ostracod carapaces embedded in a micritic matrix, along with rare conchostracans (Figs. 4D, 4E).

Interpretation: Ripple marks and syneresis cracks are concentrated in the carbonate banks. This suggests a coastal or beach environment, where wave action was present, evidenced by low-angle cross-bedding and rapid evaporation. The occurrence of fibrous gypsum suggests a saline environment. Additionally, there are trace fossils of abundant but low diversity invertebrates, preliminarily classified as the ichnogenera *Planolites* Nicholson, 1873 (Fig. 4B), and Spongeliomorpha Saporta, 1887 (Fig. 4C), also indicating shallow lacustrine conditions.

5.1.2 Distal Lake Environment (DALE)

The association of distal lake is represented by the association of low-energy facies (Fig. 5), characterized by massive reddish mudstones and interbedded greenish calcilutites (Lt) (Figs. 5B, 5C, 5D, 5E), with mudstones predominating. Occur display mottling aspect. The laminated shales exhibit fissility in rare portions. In outcrops, the mudstones appear in eroded gullies in the Imibirim region, while in other parts of the basin, such as in the city of Petrolândia, outcrops occur more vertically (Fig. 6). The mudstones commonly feature irregular pedogenic clay films, burrows, root marks, mud clasts, crystal molds and pseudomorphs, calcite-lined vugs, caliche-like pedogenic calcite nodules and stringers, as well as locally abundant, detrital muscovite. The greenish-gray massive rocks are generally coarser-grained than the red massive rocks. Red massive mudstone also contains pseudomorphic gypsum thin beds. A limited number of invertebrate fossils, including ostracods and conchostracans, are found in certain red massive mudstones, and more rarely, in some of the greenish-gray sediments.

Interpretation: Mudflats have the characteristics of distal deposits in the lake environment, with thick beds of mud formed when the lake level rises. Subaerial exposure of nearshore lacustrine rocks after a lake level drop triggered intense and prolonged mudcracking, bioturbation, growth of evaporite crystals, and pedogenic processes. The existence of irregular clay films, calcite-lined vugs, and calcite nodules and stringers in the red rocks suggests that these facies might partly represent a paleosol. Pedogenic calcite nodules indicate deposition in a hydrologically enclosed basin characterized by high evapotranspiration rates. These nodules resemble caliche, which forms in semiarid to arid climates with low sedimentation rates, seasonal precipitation, and a source of calcium ions (Hubert 1978; Retallack 1994; Demko 2004; Tanner 2010).

5.2 Taphonomy

5.2.1 Bone Representativeness and FTI

A total of 125 specimens were analyzed (Figs. 7), which represent bony and cartilaginous fishes, as well as tetrapods (archosaurs). Of this total, 40 are scales (32%), 26 are teeth (20.8%), 3 are vertebrae (2.4%), 2 are shark spines (1.6%), 1 is a humerus fragment (0.8%), one is a femur fragment (0.8%), one is an osteoderm (0.8%), one is an incomplete mandible (0.8%), and 50 are unidentified bones (40%). Most measure between 0.3 and 2.5 cm long. Larger specimens can reach up to 5 cm (osteoderms, vertebrae, shark spine). Silva et al. (2012) recorded a very complete dorsal fin spine of a hybodontid shark, which measures approximately 10 cm in length, missing only the apical portion, which is quite rare in accumulation. With regard to the post-cranial materials, few elements can be identified, mostly being indeterminate. Cranial bones were not identified. It is important to mention that the number of relative individuals (Fig. 7) was established with the presence of at least one identified bone element referring to that taxon.

5.2.2 Spearman’s Non-parametric Correlation

According to Frison and Todd (1986), when the skeletal element's FTI value is above 75, it correlates with Voorhies' Group I. When the value ranges from 75 to 50, it correlates with Group II, while elements with values below 50 are assigned to Group III. Concerning statistical values, non-parametric Spearman correlation was applied between FTI values and NISP values for the analyzed taphocenosis (Table 2).

The Spearman non-parametric correlation between the NISP and FTI values for the fossil accumulation of the Capianga Member from Ibimirim resulted in a Rho value of 0.77, with a statistically significant value (p) of 0.5. According to Araújo-Júnior et al. (2012), Spearman's non-parametric correlation values can range from -1 to +1, where values close to -1 represent a set of less transportable skeletal elements, and +1 represent more transportable skeletal elements. The value of +0.77 indicates a fossil assemblage conditioned by hydraulic selection (*sensu* Behrensmeyer, 1983; Behrensmeyer and Hook, 1992; Lyman, 1994). This result is also supported by the quantity of scales and teeth, elements marked by high transportability (Voorhies Group I), even though these elements were not included in the comparative FTI analysis. Elements such as vertebrae, femur, humerus, and incomplete mandibles are found in the calcarenite facies, associated with the edge of the lacustrine body. As expected, these parameters indicate that some skeletal elements of terrestrial tetrapods are parautochthonous, given the strong hydraulic conditioning. The high degree of transportability in skeletal elements belonging to aquatic forms is interpreted by us as being due to the cyclicity of the lithofacies of the lake system (see taphonomic model below).

5.2.3 Application of Voorhies Groups

Statistical values related to the Voorhies Groups are presented in Figure 8. Both small and medium-to-large specimens of the studied taphocoenosis were considered. Approximately 94.67% of the elements in the fossil accumulation are related to Voorhies Group I, illustrated by the high concentration of scales, teeth, and less frequently vertebrae. The remaining 5.33% are included in Voorhies Group II. It is noteworthy the absence of elements of the Group III, related to low transport capacity. This result is consistent with the FTI values obtained, where 50% of the assembly has FTI values greater than 75 (Fig. 9). Although 33.3% of the fossil assemblage has FTI values less than 50, represented by medium-to-large bone elements, the data obtained from the Spearman nonparametric correlation indicate a strong conditioning of the fossil assemblage by hydraulic currents.

5.2.4 Types of Fractures

Fossil fractures originate both in the biostratinomic phase due to weathering, predator chewing, trampling, and transport, as well as during fossil-diagenesis, during burial, due to compression and weight of overlying sedimentary layers (Shipman et al. 1981; Badam et al. 1986; Lyman 1994; Cladera et al. 2004; Medeiros 2010; Sinibaldi 2010; Bergqvist et al. 2011). Smaller bone elements mostly exhibit fractures perpendicular to the bone’s longest axis. Larger elements, such as vertebrae, partial fish mandibles, and fragments of humeri and femurs, are recognized with at least two planes of fractures, perpendicular and parallel to the major axis of the bones (Fig. 10A).

5.2.5 Abrasion marks

The abrasion marks are more present and evident on the vertebrae, appearing as uniform grooves along the fossil with rounded, smooth ends (Fig. 10B), and also on the larger bones of the fish (Figs. 11 and 13).

5.2.6 Teeth and Bones colors

The scales are the elements that show the greatest resistance to color change and do not vary with the change in lithofacies. However, the color of the teeth and vertebrae (Fig. 11) varies according to the lithofacies. Teeth may also preserve clear enamel in calcilutites, while losing enamel and becoming darker in calcarenites. The most recurrent changes in Lt are more visible alterations in larger bones (e.g. vertebrae – Fig. 11), where, in the post-burial stage, interstitial fluids rich in iron from the lithologic framework (Lt and Lm) were responsible for altering the surface color, creating a reddish and non-uniform cap along the specimens.

6. Discussion

6.1 Taphonomic Classes

All vertebrate specimens collected to date from the Capianga Member are disarticulated elements exhibiting an intense degree of reworking. These signatures may be the result of a longer duration of the pre-burial/post-mortem subaerial exposure period, suggesting a moderate to high energy level of transportability by hydraulic current and other factors, such as trampling and possibly carnivore/necrophagy chewing. As Holz and Simões (2002) emphasize, a high degree of fragmentation will only be associated with hydraulic transport if there is selection of skeletal components.

Given these premises, two taphonomic classes were identified (Fig. 12). The Class 1 is composed of isolated, semi-complete specimens (vertebrae and long bones) to rarely complete specimens (e.g. osteoderms and scales), with relative diagenetic alteration. The Class 2 is formed by a cluster of small-sized specimens, sometimes forming bonebeds, including undetermined bone fragments, isolated teeth, incomplete mandibles, and scales, exhibiting, some of them, strong weathering alteration.

6.2 Taphofacies

Three taphofacies were identified (Table 3, Figs. 13, 14, 15, 16), based on the concentration of skeletal content, alteration in fossils (such as fractures, abrasion, and color alteration), lithology, and pre-burial/post-mortem event. The predominant taphonomic features in the fossil elements of the Capianga Member include disarticulation and a high degree of fragmentation, being represented exclusively by isolated elements, ranging from millimeters to centimeters in size. Hill and Behrensmeyer (1984) consider both aquatic and subaerial disarticulation as rapid processes. The processes of reworking in lake environments are related to dry periods or floods resulting from storms, where the hydraulic current (sometimes turbidity) remobilizes the fossils before the burial period, increasing the degree of disarticulation and isolating the fossils in the sedimentary record (Seilacher 1991; Soares 2003). Skeletal remains of vertebrates with preserved bone anatomical complexity (e.g. prezygapophysis and transverse process in the vertebrae - Fig. 16) are better indicators of rapid burial (Speyer and Brett 1988).

TF-A (Fig. 13) is composed of isolated medium-sized vertebrate bioclasts with a dispersed packing degree in calcarenites associated with ostracods, conchostracans, and trace fossils. The fossils in this taphofacies are moderately fractured, with some color alteration and little abrasion. Most specimens are post-cranial bones, characterizing Voorhie's Group II, with intermediate transportability. Concerning Behrensmeyer's weathering stages (Behrensmeyer 1978), the taphofacies fall within stage 4, with fibrous texture, loose bone splinters, and open cracks. The TF-A is associated with the coastal lake environment. The reworking of these fossils can be related to the hydraulic energy of waves at the edges during dry periods and floods, evidenced by the wave marks on the calcarenites. In terms of color alteration, the fossils in TF-A show significant changes. The pre-burial/post-mortem period was interpreted as short to medium, attributing a shorter biostratinomy history to samples of this taphofacies.

TF-B (Fig. 14) is classified as a bone bed, consisting of disarticulated fragments of small specimens (microvertebrates), partial jaws, teeth and scales with no preferential orientation. The specimens of this taphofacies are small, measuring less than 2 centimeters on average. In Voorhies' classification (1969), this taphofacies belongs to the highly transportable Group I, associated with numerous fragments of small bones and scales. This group of fossils has a high potential for buoyancy, which can be easily dispersed by the hydraulic current. Among the Behrensmeyer's (1978) weathering stages, the taphofacies fall within stage 3, with rough bone surface, fibrous texture, and cracks. Most of this material shows rounding and polishing. This type of deposit presents great possibilities for time-averaging (temporal mixing), grouping non-contemporaneous individuals, which would indicate a relatively longer pre-burial/post-mortem period (Holz and Simões 2002). The TF-B is associated with the coastal lake environment.

TF-C (Figs. 15, 16) is composed of vertebrae (up to 5 cm), isolated semi-complete shark teeth and incomplete bone fish teeth (size of 5 mm) in calcilutite, dispersedly packed. They occur in the lower energy lithofacies, associated with the distal lake environment. Given the Voorhies' groups (1969), both the vertebrae and the teeth represent Group I, with easy transportability. One possible interpretation for the greenish calcilutite lithofacies is fluvial input into the lake environment during floods/storms; thus, the sediment flow would carry the remains from the lake shore to deeper regions. The post-mortem/pre-burial period is much shorter, and there is a more reduced biostratinomy history. This sediment flow occurs cohesively, moderately reworking the material, such as isolated vertebrae (Fig. 16). Weathering alterations are observed on this vertebra, such as cracked and rounded edges, presence of abrasion marks, and few fractures, characterizing Behrensmeyer's stage 2 (Behrensmeyer 1978). The teeth do not show significant enamel color alteration, due to better preservation conditions in the carbonate substrate (Sales 2005).

6.3 Taphonomic Model

After presenting all the data, it was possible to generate a representation of the lake system (Fig. 17) and a taphonomic model (Fig. 18) based on reworked bone elements, using characteristics such as concentrations of fossil assemblages, Voorhies' Groups, Fluvial Transport index (FTI), non-parametric Spearman's correlation, Behrensmeyer's Weathering Stage, types of fracture, abrasion marks, tooth and bone coloration, and disarticulation. Three taphofacies (TF-A, TF-B, and TF-C) were determined in parallel with the mapped lithofacies and description of the facies associations of the lacustrine system. The integration of these variables strengthens the proposed taphonomic model and provides new parameters in the paleogeographic reconstruction of the Middle-late Jurassic in this portion of Western Gondwana.

The interpretation of these three taphofacies reveals a multi-episode history of the lacustrine environment. The model (Fig. 18) begins with a moderate water depth, which allowed for a considerable optical zone, where ostracode and conchostracan faunas developed along the lake's edge, enabling the formation of carbonate banks by suspension in lithofacies Lc. In parallel to this, tetrapods and small bony fishes formed the taphocoenosis of taphofacies TF-A. A local variation is found in lithofacies Lc (Fig. 18C), characterizing taphofacies TF-B, which is conceptualized in this work as a bonebed, consisting of a dense and reworked accumulation of teeth, scales, mandibles, maxillae, as well as small bony fish fragments and shark teeth.

In a area further from the edge, delimited by a thermocline, the calcilutites of the Lt lithofacies were deposited (Fig. 18B). Teeth of fish and sharks that compose the taphocoenosis of taphofacies TF-C are characterized by a higher index of buoyancy, together with a caudal vertebra of a theropod exhibiting a lower degree of reworking than the vertebra found in taphofacies TF-A. This reworking process is attributed to abrasion marks resulting from hydraulic transport.

The presence of sedimentary structures such as climbing ripple cross-bedding in the lithofacies of calcarenites suggests the action of unidirectional currents. Additionally, wavy cross-stratification, exhibiting low-angle cross-lamination, consistent with wave action caused by storms, is recorded (Figs. 3E, 3G). In addition to causing greater river discharge, storms would most likely be the main reason for the intense reworking observed in the fossils of the Capianga Member, as pointed out by Seilacher (1991) and Soares (2003) for shallow marine environments. In periods when the storms cease and the climate becomes warmer, the water level of the lacustrine environment decreases (Fig. 18C), the contraction phase on the lacustrine system, concentrating $CaSO_4$, which alters the salinity of the aqueous body, possibly leading to the death of ostracods and conchostracans, which in the Capianga Member, is evidenced by the deposition of the fibrous gypsum lithofacies. At this stage, the fossils would undergo greater reworking due to remobilization and transportation, primarily by wave action, and possible scavenger activity. These storms would still occur over a short period of time and in an intense manner, with a sudden climatic change, favoring rapid decomposition and disarticulation of the entire taphocoenosis of the lacustrine environment.

7. Conclusions

The results of the sedimentological and taphonomic analyses of the Capianga Member of the Aliança Formation, achieved from a multi-scale and multi-sample perspective, allowed the interpretation of a taphonomic evolutionary model for the Capianga Member, based on the recognition of different facies according to their compositional, textural and taphonomic properties.

All the vertebrate fossils collected so far in the Capianga Member, which outcrops in the northeastern portion of the Jatobá Basin, are represented by disarticulated bone elements, showing an intense degree of reworking, resulting from a longer period of subaerial exposure, where factors such as trampling and possibly chewing by carnivores/scavengers may also have played a role.

Two taphonomic classes were identified. The Class 1 consists of isolated bones, semi-complete (vertebrae and long bones) to rarely complete bones (e.g. osteoderms and scales), with relative diagenetic alteration. The Class 2 is formed by a cluster of small-sized fossils, sometimes forming bonebeds, including undetermined bone fragments, isolated teeth, incomplete jaws, and scales.

From lithological data and the systematic collection of fossils, six lithofacies for the Capianga Member were identified: massive mudstones, laminated shales, calclutites, calcarenites, fibrous gypsum, and calcareous sandstones; as well as visualizing the lake system in two environments, coast lake environment and distal lake environment.

Through the integration of taphonomic data with lithofacies, three taphofacies were identified. These tafofacies show that the reworking events observed in the fossils of the Capianga Member were caused by the action of unidirectional currents, storm waves and the subsequent lowering of the lake level during warmer and drier periods, which remobilized the bioclasts. Thus, cycles of low and high rainfall alternated in a probable warm paleoclimate in Western Gondwana, evidenced in the strata by carbonate levels exhibiting upward ripple cross-stratification, massive mudstones and centimetric levels of gypsum. Future studies involving the geochemistry of carbonates, particularly in the calcarenite and calcilutite facies, will be extremely important to reinforce the hypotheses described here about the Jurassic climate in this part of Gondwana

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REFERENCES

ABDUL AZIZ, H., SANZ-RUBIO, E., CALVO, J.P., HILGEN, F.J., and KRIJGSMAN, W., 2003, Palaeoenvironmental reconstruction of a middle Miocene alluvial fan to cyclic shallow lacustrine depositional system in the Calatayud Basin (NE Spain): Sedimentology, v. 50, p. 211–236, doi: 10.1046/j.1365-3091.2003.00544.x.

ARAÚJO-JÚNIOR, H.I.D., BISSARO JÚNIOR, M.C., SANTOS, T.T.D., ALVES, R.D.S., and BERGQVIST, L.P., 2012, Tafonomia da megafauna pleistocênica brasileira: fluvial transport index (FTI) em análises de representatividade óssea: REVISTA BRASILEIRA DE PALEONTOLOGIA, v. 15, p. 95–104, doi: 10.4072/rbp.2012.1.08.

ANADÓN, P., CABRERA, LL., JULIÀ, R., and MARZO, M., 1991, Sequential Arrangement and Asymmetrical Fill in the Miocene Rubielos de Mora Basin (Northeast Spain), *in* Anadón, P., Cabrera, Li., and Kelts, K., eds., Lacustrine Facies Analysis: Wiley, p. 257–275, doi: 10.1002/9781444303919.ch13.

ASSINE, M.L., 2007, Araripe Basin: Boletim de Geociencias da Petrobras, v. 15, p. 371– 389

BADAM, G.L., GANJOO, R.K., and SALAHUDDIN, 1986, Preliminary taphonomical studies of some Pleistocene fauna from the Central Narmada Valley, Madhya Pradesh, India: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 53, p. 335–348, doi: 10.1016/0031-0182(86)90067-2.

BEHRENSMEYER, A.K., 1978, Taphonomic and ecologic information from bone weathering: Paleobiology, v. 4, p. 150–162, doi: 10.1017/S0094837300005820.

BEHRENSMEYER, A.K., 1983, Patterns of natural bone distribution on recent land surfaces: implications for archaeological site formation. In: J. Clutton-Brock & C. Grigson (eds.) Animals and archaeology: 1. hunters and their prey, British Archaeological Reports International Series, p. 93-106.

BEHRENSMEYER, A.K. and HOOK, R.W., 1992, Paleoenvironmental context and taphonomic modes. In: A.K. Behrensmeyer; J.D. Damuth; W.A. DiMichele; R. Potts; H.D. Sues & S.L. Wing (eds.) Terrestrial ecosystems through time: evolutionary paleoecology of terrestrial plants and animals, University of Chicago Press, p. 15-136.BEHRENSMEYER, A.K., 1991, Terrestrial Vertebrate Accumulations, *in* Allison, P.A. and Briggs, D.E.G., eds., Taphonomy: Topics in Geobiology, Springer US, Boston, MA, p. 291–335, doi: 10.1007/978-1-4899-5034-5_6.

BERGQVIST, L., ALMEIDA, E., and ARAÚJO JÚNIOR, H., 2011, Tafonomia da assembleia fossilífera de mamíferos da “Fenda 1968”, bacia de São José de Itaboraí, Estado do Rio de Janeiro, Brasil: REVISTA BRASILEIRA DE PALEONTOLOGIA, v. 14, p. 75–86, doi: 10.4072/rbp.2011.1.08.

BOHACS, K.M., CARROLL, A.R., NEAL, P.J. and MANKIEWICZ, P.J., 2000., Lake-Basin Type, Source Potential, and Hydrocarbon Character: an Integrated Sequence-Stratigraphic–Geochemical Framework, 2000, *in* Lake Basins Through Space and Time: American Association of Petroleum Geologists, p. 3–33, doi: 10.1306/St46706C1

BOHACS, K.M., CARROLL, A.R., and NEAL, J.E., 2003, Lessons from large lake systems-Thresholds, nonlinearity, and strange attractors, *in* Extreme Depositional Environments: Mega End Members in Geologic Time: Geological Society of America, doi: 10.1130/0-8137-2370-1.75

BORDY, E.M., and CATUNEANU, O., 2001, Sedimentology of the upper Karoo fluvial strata in the Tuli Basin, South Africa: Journal of African Earth Sciences, v. 33, p. 605–629, doi: 10.1016/S0899-5362(01)00090-2.

BRAUN, O.P.G., 1966, Estratigrafia dos sedimentos da parte interior de região nordeste do Brasil (Bacias de Tucano-Jatobá, Mirandiba e Araripe). Rio de Janeiro, Departamento Nacional de Produção Mineral. Divisão de Geologia e Mineralogia. p. 75. (Boletim 236).

CAMPOS NETO, O.A., SOUZA-LIMA, W. and CRUZ, F.E.G., 2007, Bacia de Sergipe-Alagoas. Boletim de Geociências da Petrobras, n. 2, p. 405-415. (Boletim 15).

CARDOSO, R.N., 1966, Conchostráceos do Grupo Bahía: Brasil. Boletim do Instituto de Geologia, n. 2, p. 1-76. (Boletim 01).

CARVALHO, I.S., 1993, Os conchostráceos fósseis das Bacias Interiores do Nordeste do Brasil. Programa de Pós-Graduação em Geologia, Universidade Federal do Rio de Janeiro Rio de Janeiro, Tese de Doutorado, 319p.

CARVALHO, A.R.D.A., OLIVEIRA, G.R., and BARRETO, A.M.F., 2021, New Crocodylomorpha remains from the late jurassic Aliança Formation (Dom João stage), Jatobá Basin: Journal of South American Earth Sciences, v. 109, p. 103256, doi: 10.1016/j.jsames.2021.103256.

CAVINATO, G.P., CARUSI, C., DALL'ASTA, M., MICCADEI, E., and PIACENTINI, T., 2002, Sedimentary and tectonic evolution of Plio–Pleistocene alluvial and lacustrine deposits of Fucino Basin (central Italy): Sedimentary Geology, v. 148, p. 29–59, doi: 10.1016/S0037-0738(01)00209-3.

CESERO, P. and PONTE, F.C., 1972, Análise comparativa da paleogeologia dos litorais atlânticos, brasileiro e africano. Boletim de Geociências da Petrobras, Rio de Janeiro, n. 2, p. 1-18. (Boletim 11).

CLADERA, G., RUIGOMEZ, E., JAUREGUIZAR, E. O., BOND, M. and LÓPEZ, G., 2004., Tafonomía de la Gran Hondonada (Formación Sarmiento, Edad-mamífero Mustersense, Eoceno Medio) Chubut, Argentina. Ameghiniana, 41(3): 315-330.

COSTA, I.P., BUENO, G.V., MILHOMEM, P.S., SILVA, H.S.L.E. and KOSIN, M.D., 2007, Sub-bacia de Tucano Norte e Bacia de Jatobá. Boletim de Geociências da Petrobras, n. 2, p. 445-453. (Boletim 15).

DA ROSA, Á.A.S., and GARCIA, A.J.V., 2000, Palaeobiogeographic aspects of northeast Brazilian basins during the Berriasian before the break up of Gondwana: Cretaceous Research, v. 21, p. 221–239, doi: 10.1006/cres.2000.0209.

DAVISON, I., 1999, Tectonics and hydrocarbon distribution along the Brazilian South Atlantic margin: Geological Society, London, Special Publications, v. 153, p. 133–151, doi: 10.1144/GSL.SP.1999.153.01.09.

DE OLIVEIRA, L.M., OLIVEIRA, É.V., and FAMBRINI, G.L., 2022, The first dinosaur from the Jurassic Aliança Formation of northeastern Brazil, west Gondwana: a basal Neotheropoda and its age and paleobiogeographical significance: Journal of South American Earth Sciences, v. 116, p. 103835, doi: 10.1016/j.jsames.2022.103835.

DODSON, P., 1971, Sedimentology and taphonomy of the Oldman Formation (Campanian), Dinosaur Provincial Park, Alberta (Canada): Palaeogeography, Palaeoclimatology, Palaeoecology, v. 10, p. 21–74, doi: 10.1016/0031-0182(71)90044-7.

DUNHAM, R.J., 1962, Classification of Carbonate Rocks According to Depositional Texture. In: Ham, W.E. (eds.). Classification of Carbonate Rocks, AAPG, Tulsa, p. 108-121.

FAMBRINI, G.L., JUNIOR, A.M.B., OLIVEIRA, E.V., DA SILVA FILHO, W.F., and NEUMANN, V.H.M.L., 2023, Sedimentology and stratigraphy of silicified fossil trunks bearing Missão Velha Formation (late jurassic-early cretaceous), Araripe Basin, Northeastern Brazil: Paleoclimatic implications: Journal of South American Earth Sciences, v. 131, p. 104624, doi: 10.1016/j.jsames.2023.104624.

FAMBRINI, G.L., NEUMANN, V.H.M.L., LEMOS, D.R., ARAÚJO, J.T., LIMA-FILHO, M.F. and SILVA-FILHO, W.F., 2010, Stratigraphy and sedimentology of the Rift Initiation to Rift Climax stages of the Araripe Basin, Northeastern Brazil: new considerations. In: International Sedimentological Congress, 18, 2010. Abstracts Volume, Mendoza, Argentina. p. 333.

FAMBRINI, G.L., LEMOS, D.R.D., TESSER JR., S., ARAÚJO, J.T.D., SILVA-FILHO, W.F.D., SOUZA, B.Y.C.D., and NEUMANN, V.H.D.M.L., 2011, Estratigrafia, arquitetura deposicional e faciologia da formação Missão Velha (Neojurássico-Eocretáceo) na área-tipo, bacia do Araripe, nordeste do Brasil: exemplo de sedimentação de estágio de início de rifte a clímax de rifte: Geologia USP. Série Científica, v. 11, p. 55–87, doi: 10.5327/Z1519-874X2011000200004.

FAMBRINI, G.L., NEUMANN, V.H.M.L., GUZMÁN, J., OLIVEIRA, E.V., PIOVESAN, E.K., and SIAL, A.N., 2016, Sequência de Início de Rift (Grupo Brotas) da Bacia de Jatobá: resultados preliminares. In: Congresso Brasileiro de Geologia, 48, 2016, Porto Alegre - RS. Anais, v. único. Meio digital.

FAMBRINI, G.L., NEUMANN, V.H.D.M.L., BARROS, C.L.D., SILVA, S.M.O.A.D., GALM, P.C., and MENEZES FILHO, J.A.B.D., 2013, Análise estratigráfica da Formação Brejo Santo, Bacia do Araripe, Nordeste do Brasil: implicações paleogeográficas: Geologia USP. Série Científica, v. 13, p. 3–28, doi: 10.5327/Z1519-874X201300040001.

FAMBRINI, G.L., OLIVEIRA, É.V., SOUSA, P.C.S.D., DE OLIVEIRA, L.M., QUEIROZ, R.G.B., ESPÍNDOLA, M.S.D., NEUMANN, V.H.D.M.L., and BARRETO, A.M.F., 2023, O Grupo Brotas da Bacia de Jatobá: sequência de início de rifte do Sistema Recôncavo-Tucano-Jatobá: Geologia USP. Série Científica, v. 23, p. 103–129, doi: 10.11606/issn.2316-9095.v23-214391.

FAMBRINI, G.L., DA CUNHA SILVESTRE, D., DE MENEZES-FILHO, J.A.B., DA COSTA, I.C., and NEUMANN, V.H.D.M.L., 2019, Architectural and facies characterization of the Aptian fluvial Barbalha Formation, Araripe Basin, NE Brazil: Geological Society, London, Special Publications, v. 488, p. 119–150, doi: 10.1144/SP488-2017-275.

FLESSA, K.W., KOWALEWSKI, M., and WALKER, S.E., 1992, Post-Collection Taphonomy: Shell Destruction and the Chevrolet: PALAIOS, v. 7, p. 553, doi: 10.2307/3514853.

GRADZINSKY, R., 1970, Sedimentation of dinosaur bearing Upper Cretaceous deposits of the Memegt Basin, Gobi Desert. Palaeontologica Polonica, 21: 147-210.

GOODWIN, M.B., IRMIS, R.B., WILSON, G.P., DEMAR, D.G., MELSTROM, K., RASMUSSEN, C., ATNAFU, B., ALEMU, T., ALEMAYEHU, M., AND CHERNET, S.G., 2019, The first confirmed sauropod dinosaur from Ethiopia discovered in the Upper Jurassic Mugher Mudstone: Journal of African Earth Sciences, v. 159, p. 103571, doi: 10.1016/j.jafrearsci.2019.103571.

GORE, P.J.W., 1989, Toward a model for open- and closed-basin deposition in ancient lacustrine sequences: The Newark Supergroup (Triassic-Jurassic), Eastern North America: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 70, p. 29–51, doi: 10.1016/0031-0182(89)90078-3.

GUZMÁN-GONZÁLEZ, J., PIOVESAN, E.K., FAMBRINI, G.L., and OLIVEIRA, É.V., 2016, Non-marine Ostracoda from the Aliança Formation in the north-central portion of the Jatobá

Basin, Northeastern Brazil: Revista Brasileira de Paleontologia, v. 19, p. 15–24, doi: 10.4072/rbp.2016.1.02.

GUZMÁN-GONZÁLEZ, J., SIAL, A.N., PIOVESAN, E.K., OLIVEIRA, E.V., and FAMBRINI, G.L., 2020, Paleolimnological reconstruction of a marginal area of Jurassic Capianga Lake, Jatobá Basin, northeast Brazil: Journal of Paleolimnology, v. 63, p. 113–128, doi: 10.1007/s10933-019-00105-0.

HAMMER, Ø., HARPER, DAVID, A.T. and RYAN, P., 2001. Past: paleontological statistics software package for educaton and data anlysis. Palaeontologia electronica, v. 4, n. 1, p. 1.

HEERMANCE, R.V., PULLEN, A., KAPP, P., GARZIONE, C.N., BOGUE, S., DING, L., and SONG, P., 2013, Climatic and tectonic controls on sedimentation and erosion during the Pliocene-Quaternary in the Qaidam Basin (China): Geological Society of America Bulletin, v. 125, p. 833–856, doi: 10.1130/B30748.1.

HILL, A., and BEHRENSMEYER, A.K., 1984, Disarticulation patterns of some modern East African mammals: Paleobiology, v. 10, p. 366–376, doi: 10.1017/S0094837300008332.

HOLZ, M., and BARBERENA, M.C., 1994, Taphonomy of the south Brazilian Triassic paleoherpetofauna: pattern of death, transport and burial: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 107, p. 179–197, doi: 10.1016/0031-0182(94)90170-8.

HOLZ, M. and SIMÕES, M.G., 2002, Elementos fundamentais de tafonomia, Ed. UFRGS, Porto Alegre.

JONES, S.J., FROSTICK, L.E., and ASTIN, T.R., 2001, Braided stream and flood plain architecture: the Rio Vero Formation, Spanish Pyrenees: Sedimentary Geology, v. 139, p. 229–260, doi: 10.1016/S0037-0738(00)00165-2.

KUCHLE, J., SCHERER, C.M.D.S., BORN, C.C., ALVARENGA, R.D.S., and ADEGAS, F., 2011, A contribution to regional stratigraphic correlations of the Afro-Brazilian depression – The Dom João Stage (Brotas Group and equivalent units – Late Jurassic) in Northeastern Brazilian sedimentary basins: Journal of South American Earth Sciences, v. 31, p. 358–371, doi: 10.1016/j.jsames.2011.02.007.

LYMAN, R.L., 1994, Vertebrate Taphonomy: Cambridge University Press, doi: 0.1017/CBO9781139878302

MAGNAVITA, L.P., and CUPERTINO, J.A., 1987, Concepção atual sobre as bacias de Tucano e Jatobá, Nordeste do Brasil. Boletim de Geociências da Petrobras, n. 2, p. 119-134. (Boletim 1).

MAGNAVITA, L.P., DAVISON, I., and KUSZNIR, N.J., 1994, Rifting, erosion, and uplift history of the Recôncavo-Tucano-Jatobá Rift, northeast Brazil: Tectonics, v. 13, p. 367–388, doi: 10.1029/93TC02941.

MAGNAVITA, L.P., SZATMARI, P., CUPERTINO, J.A., DESTRO, N. and ROBERTS, D.G., 2012, The Recôncavo Basin. In: Roberts, D.G. and Bally, A.W (eds.). Regional Geology and Tectonics: Phanerozoic Rift Systems and Sedimentary Basins. Amsterdam: Elsevier Science, p. 383-420.

MALKA, M., OLSEN, P.E. and CHRISTIE-BLICK, N., 2003, Lacustrine facies typology in the Triassic-Jurassic rifts of eastern North America and Greenland compared to that of the Eocene

Green River Formation of Wyoming. Northeastern Section. IN: 38th Annual Meeting (March 27-29, 2003). The Geological Society of America (GSA), Session No.

MEDEIROS, M.A., 2010, Fossildiagênese. In: Carvalho, Ismar de Souza (eds.). Paleontologia: conceitos e métodos, v. 1, 3 ed. Rio de Janeiro: Editora Interciência.

MIALL, A.D., 1978, Lithofacies types and vertical profile models in braided-rivers deposits: a summary. In: Miall A.D. (eds.) Fluvial Sedimentology. Calgary, Canadian Society of Petroleum Geologists, p. 597-604.

MIALL, A.D., 1996, The geology of fluvial deposits: sedimentary facies, basin analysis and petroleum geology. Berlin, Springer, 582 p.

MIALL, A.D., 2006, The Geology of Fluvial Deposits: Springer Berlin Heidelberg, Berlin, Heidelberg, doi: 10.1007/978-3-662-03237-4

MIALL, A., 2014, Fluvial Depositional Systems: Springer International Publishing, Cham, doi: 10.1007/978-3-319-00666-6

MOUNGUENGUI, M., LANG, J., and GUIRAUD, M., 2008, Sedimentary dynamics and extensional structuring related to early Cretaceous rifting of Neocomian and Barremian deposits of the interior basin of Gabon: Journal of African Earth Sciences, v. 51, p. 239–256, doi: 10.1016/j.jafrearsci.2008.01.008.

MYERS, T.S., and STORRS, G.W., 2007, Taphonomy of the Mother’s Day Quarry, upper Jurassic Morrison Formation, South-Central Montana, USA: PALAIOS, v. 22, p. 651–666, doi: 10.2110/palo.2005.p05-123r.

NEUMANN, V.H.M.L., ROCHA, D.E.G.A., MORAES, A.S., SIAL, A.N., CASTRO, M.T., BARBOSA, J.A., FAMBRINI, G.L. and CARVALHO, R.R., 2010, Microfácies carbonáticas e comportamento isotópico de C e O nos calcários laminados aptianos lacustres da Serra Negra, Bacia do Jatobá, Nordeste do Brasil. Estudos Geológicos, 20(1): 89-100.

NEUMANN, V.H.M.L., ROCHA, D.E.G.A., VORTISCH, W., GRATZER, R., LIMA-FILHO, M., BARBOSA, J.A. and FAMBRINI, G.L., 2013, Sedimentary Facies and Palaeoenvironmental Records of an Intracratonic Basin Lake: Aptian Lacustrine Crato Formation, Jatobá Basin, NE Brazil. In: AAPG Annual Convention and Exhibition. Pittsburgh: AAPG, 2013, v. 50882.

NEUMANN, V.H., and ROCHA, D.E.G.A., 2014, Stratigraphy of the Post-Rift Sequences of the Jatobá Basin, Northeastern Brazil, *in* Rocha, R., Pais, J., Kullberg, J.C., and Finney, S., eds., STRATI 2013: Springer Geology, Springer International Publishing, Cham, p. 553–557, doi: 10.1007/978-3-319-04364-7_106

NEUMANN, V.H., MIRANDA, T.S.D., FIGUEIRAS, C.F.C. and AMARAL, C.D.A., 2017, Geologia e recursos minerais da Folha Poço da Cruz, SC.24- X-A-VI Estados de Pernambuco e de Alagoas. CPRM-Serviço Geológico do Brasil, p. 1-62.

PERARO, A.A., 1995, Caracterização sísmica do tectonismo transcorrente na Bacia do Jatobá. In: 4TH International Congress of the Brazilian Geophysical Society. Rio de Janeiro: Anais. p.1-3.

PONTE, F.C., AND ASMUS, H.E., 1978, Geological framework of the Brazilian continental margin: Geologische Rundschau, v. 67, p. 201–235, doi: 10.1007/BF01803262.

PONTE, F.C., 1992, Sistemas deposicionais na Bacia do Araripe, nordeste do Brasil. In: Simpósio sobre as bacias cretácicas brasileiras, 2. Rio Claro: Anais. p. 81–84.

PONTE, F.C., 1994, Extensão Paleogeográfica da Bacia do Araipe no Mesocretáceo. In: Simpósio sobre o cretáceo do brasil, 3. Rio Claro: Anais. p.131-135.

PONTE, F.C. and PONTE FILHO, F.C., 1996a, Estrutura geológica e evolução tectônica da Bacia do Araripe. Recife: DNPM, 4º e 10º Distritos Regionais, Delegacias do Ministério das Minas e Energia em Pernambuco e Ceará.

PONTE, F.C. and PONTE FILHO., 1996b. Evolução tectônica e classificação da Bacia do Araripe. In: Simpósio sobre o cretáceo do brasil, 4. Águas de São Pedro: Boletim UNESP, p.123-133.

ROCHA, D.E.G.A. and AMARAL, C.A., 2007, Caracterização Geologica e Geométrica dos Aquiferos (Meta B). In: Costa, W. D and Feitosa, F. A. C. Hidrogeologia da Bacia Sedimentar do Jatobá: Sistema Aqüífero Tacaratu/Inajá. Ministério de Minas e Energia - Ministério da Ciênica e Tecnologia.

ROCHA, D.E.G.A., 2011, Caracterização do intervalo carbonático aptiano da Bacia do Jatobá, NE do Brasil. Programa de Pós-Graduação em Geociências, Universidade Federal de Pernambuco, Tese de Doutorado em Geociências - Centro de Tecnologia e Geociências, UFPE, 124 p.

SÁEZ, A., and CABRERA, L., 2002, Sedimentological and palaeohydrological responses to tectonics and climate in a small, closed, lacustrine system: Oligocene As Pontes Basin (Spain): Sedimentology, v. 49, p. 1073–1094, doi: 10.1046/j.1365-3091.2002.00490.x.

SALES, A.M.F., 2005, Análise tafonômica das ocorrências fossilíferas de macroinvertebrados do Membro Romualdo (Albiano) da Formação Santana, Bacia do Araripe, NE do Brasil: significado estratigráfico e paleoambiental. Programa de Pós-Graduação em Geociências, Tese de Doutorado. Universidade de São Paulo

SCHALLER, H., 1969, Revisão Estratigráfica da Bacia de Sergipe-Alagoas. Boletim Técnico da Petrobrás, 12(1): 21 -86.

SCHERER, C.M.D.S., JARDIM DE SÁ, E.F., CÓRDOBA, V.C., SOUSA, D.D.C., AQUINO, M.M., and CANELAS CARDOSO, F.M., 2014, Tectono-stratigraphic evolution of the Upper Jurassic–Neocomian rift succession, Araripe Basin, Northeast Brazil: Journal of South American Earth Sciences, v. 49, p. 106–122, doi: 10.1016/j.jsames.2013.10.007.

SEILACHER, A., ANDALIB, F., DIETL, G. and GOCH, H., 1976, Preservational history of compressed Jurassic ammonites from southern Germany. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 152(3): 307-356.

SEILACHER, A., 1991, Events and their signatures - an overview In: Einsele, G.; Ricken, W. and Seilacher, A. (eds.). Cycles and Events in Stratigraphy. Berlín, Springer-Verlag, p. 222-226.

SILVA, M.C., CARVALHO, M.S.S. BARRETO, A.M.F. and CARVALHO, I.S.C., 2012, Paleoictiofauna da Formação Aliança (Jurássico Superior), Bacia de Jatobá, Nordeste do Brasil. In: Carvalho, I.S.; Srivastava, N.K.; Strohschoen, O. and Lana, C.C. (eds.). Paleontologia: cenários de vida, vol.4, Rio de Janeiro: Interciência, p. 595-608.

SIMÕES, M.G. and HOLZ, M., 2000, Tafonomia: processos e ambientes de fossilização. In: CARVALHO, I.S. (ed.). Paleontologia. Rio de Janeiro: Ed. Interciência. p.19-46.

Sinibaldi, R.W. *2010*. What Your Fossils Can Tell You: *Vertebrate Morphology*, Pathology, and Cultural Modification. University Press of Florida.

SHIPMAN, P. 1981, Applications of scanning electron microscopy to taphonomic problems. Annals of the New York Academy of Sciences, 276.

SMITH, R.M.H., 1993, Vertebrate Taphonomy of Late Permian Floodplain Deposits in the Southwestern Karoo Basin of South Africa: PALAIOS, v. 8, p. 45, doi: 10.2307/3515221.

SOARES, M.B.A., 2003, Taphonomic model for the Mesosauridae assemblage of the Irati Formation (Paraná Basin, Brazil). Geologica Acta: an international earth science journal, 1(4): 349-361.

SOUSA, P.C.S.D., DE OLIVEIRA, L.M., QUEIROZ, R.G.B., ESPÍNDOLA, M.D.S., OLIVEIRA, É.V., and FAMBRINI, G.L., 2024, The Boipeba member in the Jatobá Rift (northeastern Brazil): Occurrence, facies characterization and palaeoenvironmental implications: Journal of South American Earth Sciences, v. 133, p. 104676, doi: 10.1016/j.jsames.2023.104676.

SPEYER, S.E., and BRETT, C.E., 1988, Taphofacies models for epeiric sea environments: Middle Paleozoic examples: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 63, p. 225–262, doi: 10.1016/0031-0182(88)90098-3.

TALBOT, M.R. and ALLEN, P.A., 1996, Lakes. In: H. G. Reading (eds.), Sedimentary environments: processes, facies and stratigraphy. New Jersey: Blackwell Science. p. 83-124.

TEISSERENC, P., AND VILLEMIN, J., 1989, Sedimentary Basin of Gabon—Geology and Oil Systems, *in* Divergent/Passive Margin Basins: American Association of Petroleum Geologists, doi: 10.1306/M48508C3.

UZUNIDIS, A., PINEDA, A., JIMÉNEZ-MANCHÓN, S., XAFIS, A., OLLIVIER, V., and RIVALS, F., 2021, The impact of sediment abrasion on tooth microwear analysis: an experimental study: Archaeological and Anthropological Sciences, v. 13, p. 134, doi: 10.1007/s12520-021-01382-5.

VALENÇA, L.M.M., NEUMANN, V.H.M.L. and Mabesoone, J.M., 2003, An overview on CallovianCenomanian intracratonic basins of Northeast Brazil: Onshore stratrigraphic record of the opening of the southern Atlantic. Geologica Acta, 1(3): 261- 275.

VIANA, C.F and VAN HINTE, J.E., 1966, Stratigraphic distribution of Ostracoda in the Bahia Supergroup (Brazil). In: West african micropaleontological colloquium, 2, Ibadan, 1965, Proceedings, Leiden, p. 240-256.

VIANA, C.F., GAMA JUNIOR, E.G., SIMÕES, I.A., MOURA, J.A., FONSECA, J.R. AND ALVES, R.J., 1971, Revisão estratigráfica da Bacia Recôncavo/Tucano. Boletim Técnico da Petrobras, 14(3- 4): 157-192. (Boletim 14).

VOORHIES, M.R., 1969, Taphonomy and Population Dynamics of an Early Pliocene Vertebrate Fauna, Knox County, Nebraska: University of Wyoming, Laramie, WY, doi: 10.2113/gsrocky.8.special_paper_1.1

CAPTIONS

FIG. 1.—Geologic map of the Jatobá. **A**) Map of South America. **B**) Location of the Jatobá Basin in the state of Pernambuco. **C**) Geologic map of the Jatobá Basin with the location of the outcrops in the Ibimirim region. **D**) Zoom in on the geological map of the Jatobá Basin in the Ibimirim region. **E**) Local geological map of the Macambira and Modubim outcrops.

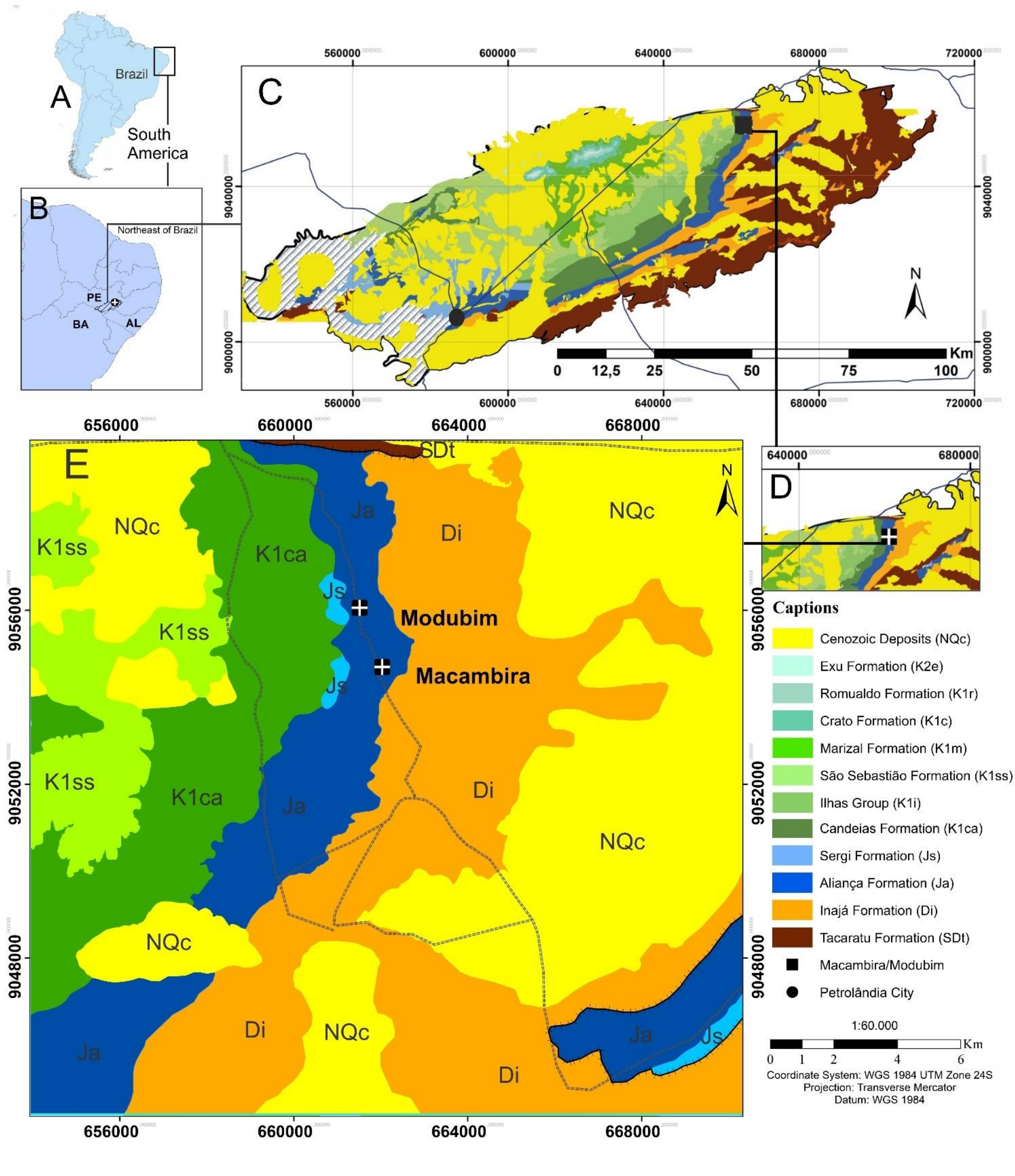


FIG. 2.—Schematic columnar sections of the Capianga Member. **A-E**) outcrop of Macambira section. **F-J**) outcrop Modubim section.

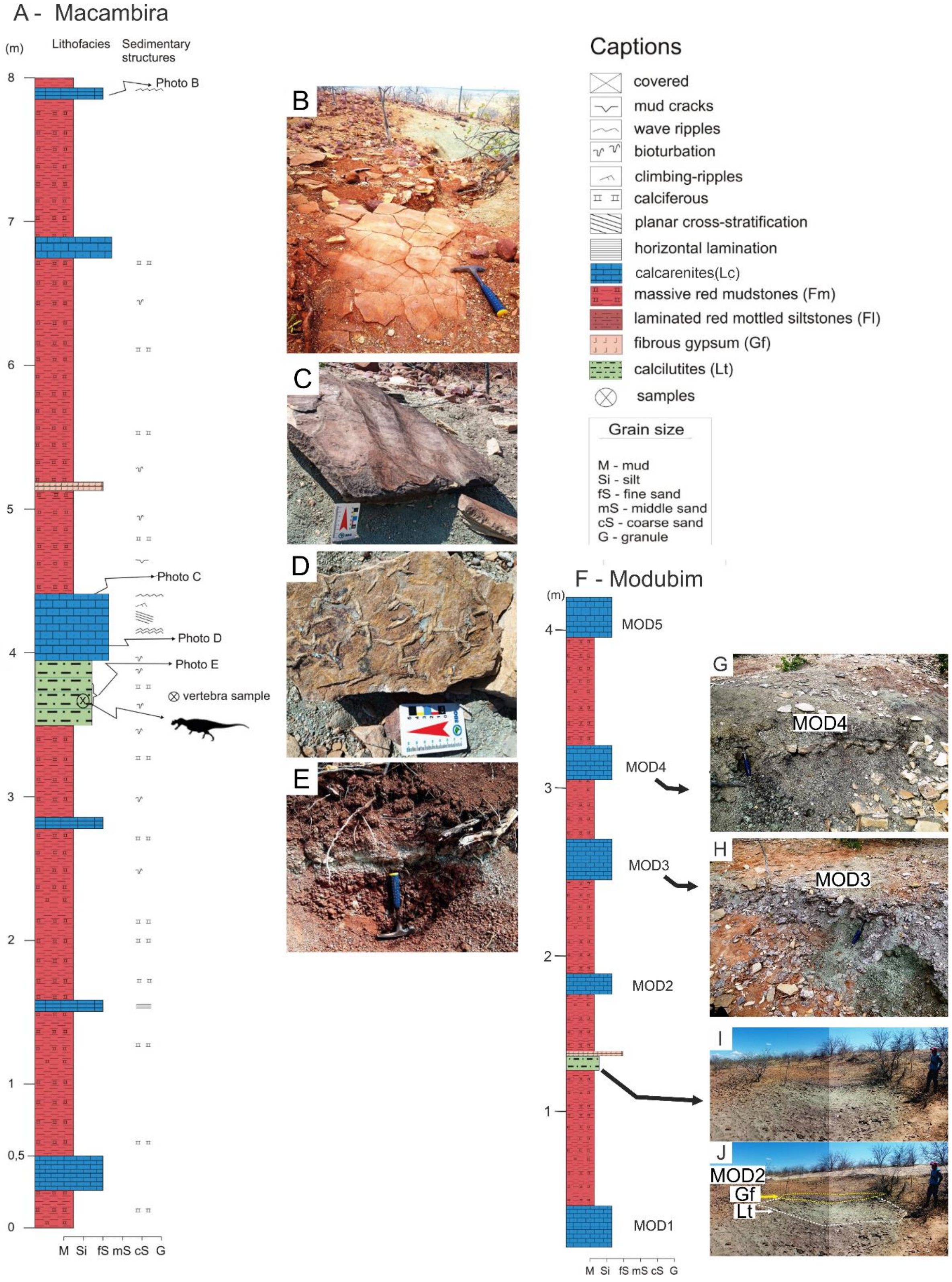


FIG. 3.—Facies identified in the Capianga Member. **A**) Calciferous sandstones (Scl) followed by massive mudstones (Fm). **B**) Calcilutites (Lt), massive mudstones (Fm) and laminated shales (Fl). **C**) Calcarenites (Lc) with cracks and wavy marks. **D**) Calcarenites (Lc) with crevices and fibrous gypsum (Gf) filling syneresis cracks. **E**) Intercalation of Calcarenites (Lc) and Calcilutites (Lt). **F**) Intercalation of Calcarenites (Lc) and small layers of fibrous Gypsum (Gf). **G**) Calcarenites with climbing-ripples.

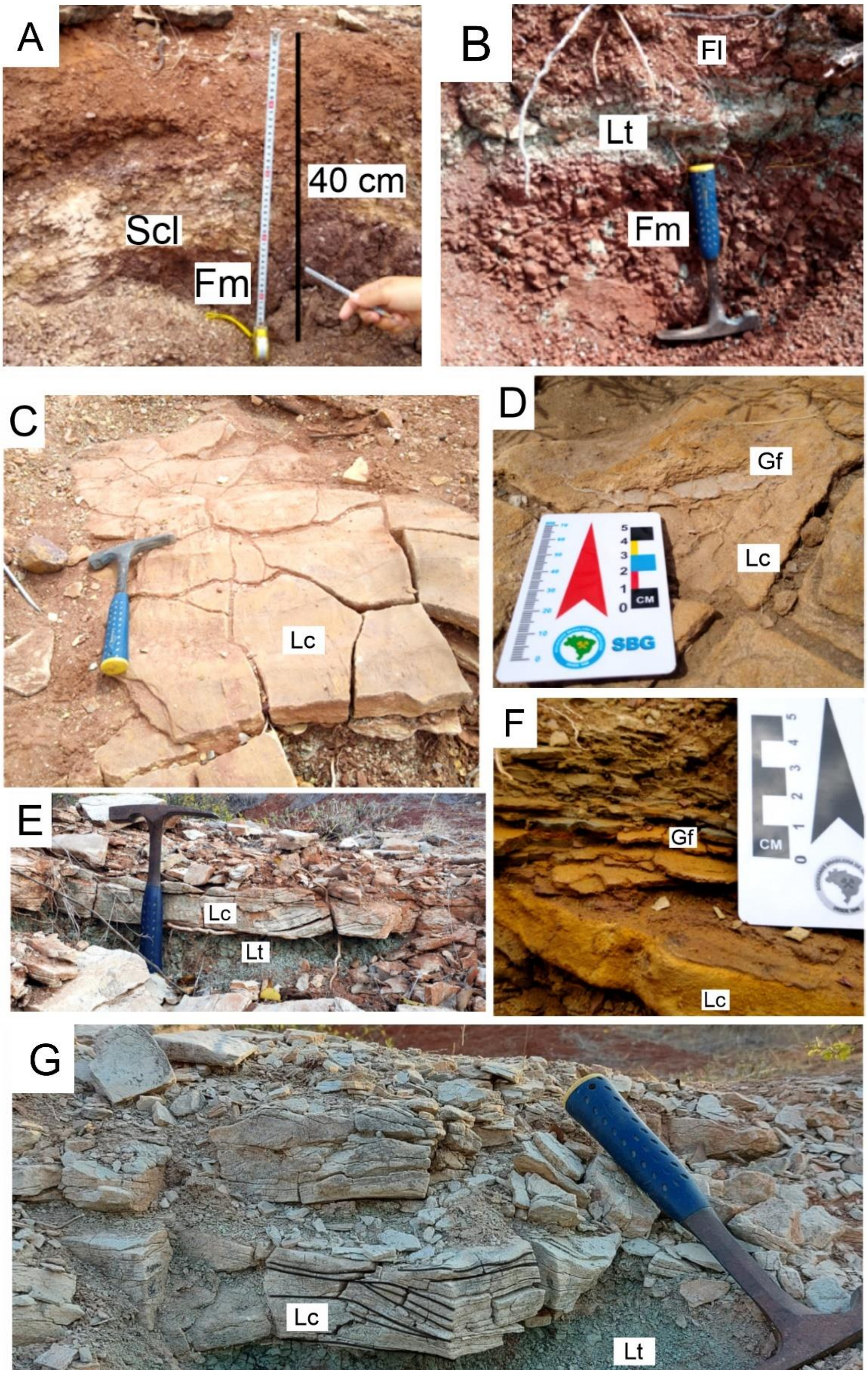


FIG. 4.—Association of lake margin facies, Wave-dominated Coastal Lake Environment (WCLE). **A**) Macambira Outcrop. **B**) *Planolites* trace fossil. **C**) Spongeliomorpha trace fossil. **D**) Very compacted skeletal Ostracod Grainstone and micrite calcite (Mc), in the east part occurs a set of ostracode valves in cup-in-cup structure. **E**) Same facies as picture D under crossed nicols lighting. D and E Scale bar: 1mm.

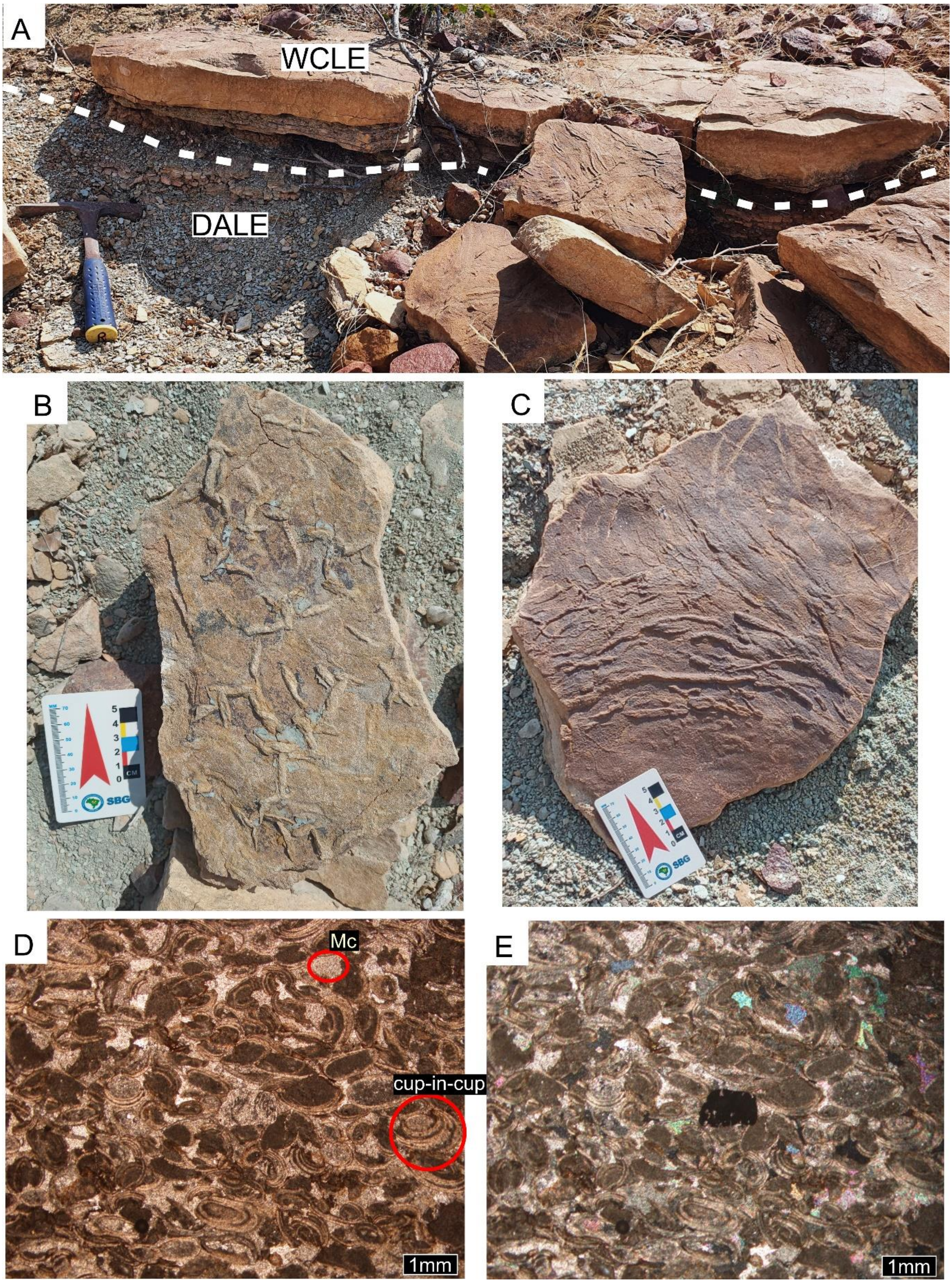


FIG. 5.—Association of low-energy facies, Distal Lake Environment (DALE). **A**) Macambira Outcrop. **B**) Calcilutites with rare quartz grains on a micritic matrix. **C**) Same facies as picture B under crossed nicols lighting. **D**) Calcilutites laminated on a micritic matrix. **E**) Same facies as picture D under crossed nicols lighting; B-E Scale bar: 200µm.

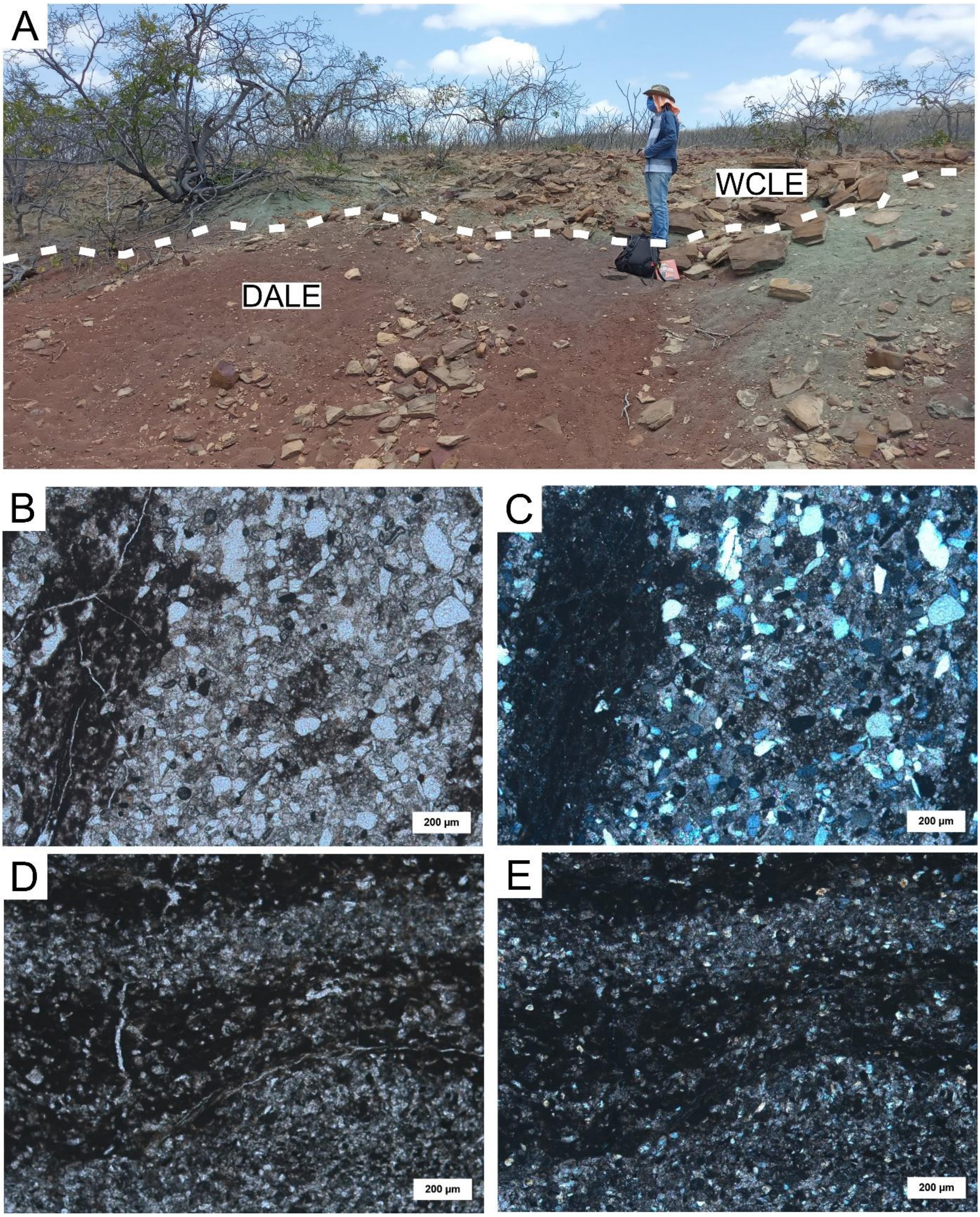


FIG. 6.—Petrolândia Outcrop, mudstones (Fm and Fl) and subordinate calculutites (Lt).

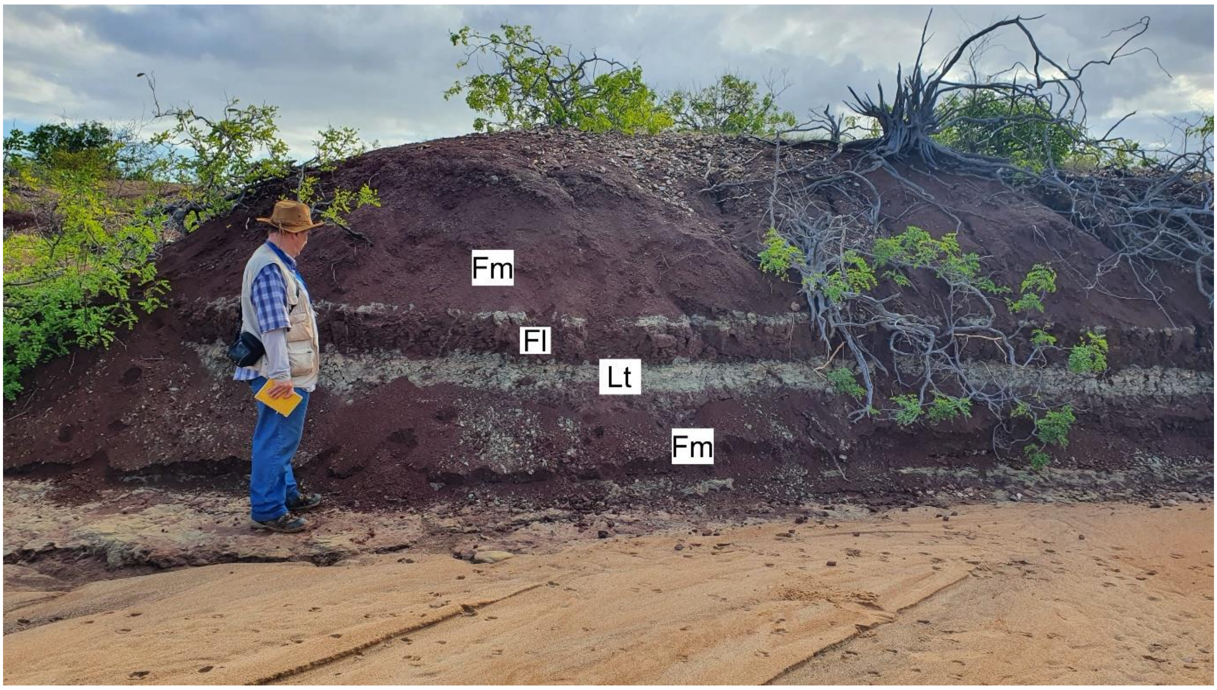


FIG. 7.—Relative number of individuals per taxon in the fossiliferous assemblage analyzed from the Capianga Member.

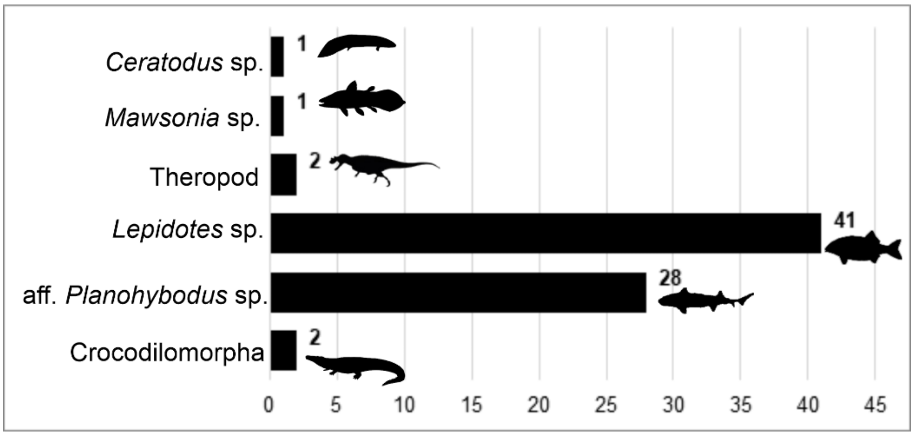


FIG. 8.—Values, in percentages, of elements related to the Voorhies groups

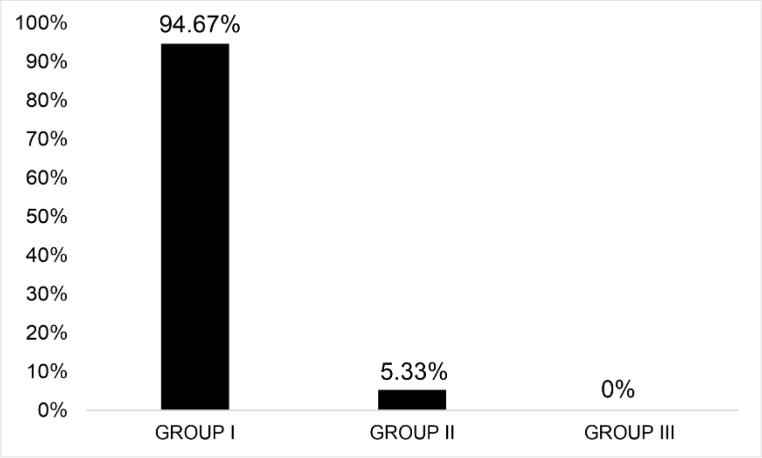


FIG. 9.—Percentage values of elements according to the Fluvial Transport Index (FTI).

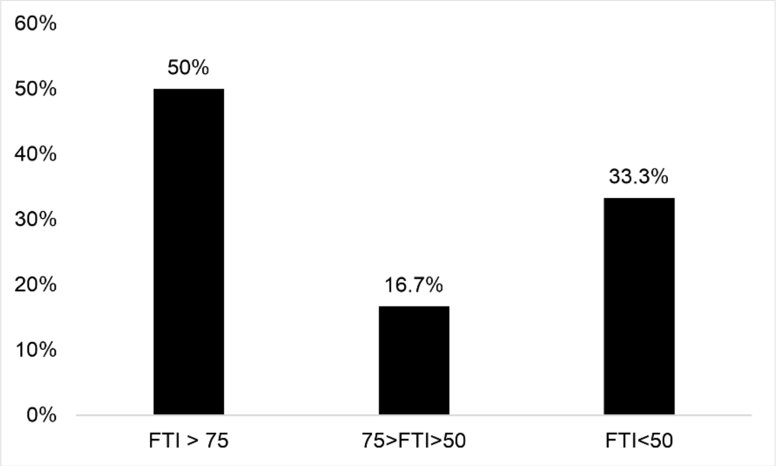


FIG. 10.—Middle caudal vertebra of the basal theropod Dilophosauridae. **A**) Fractures (frt). **B**) Abrasion marks (ab). Scales 1cm.

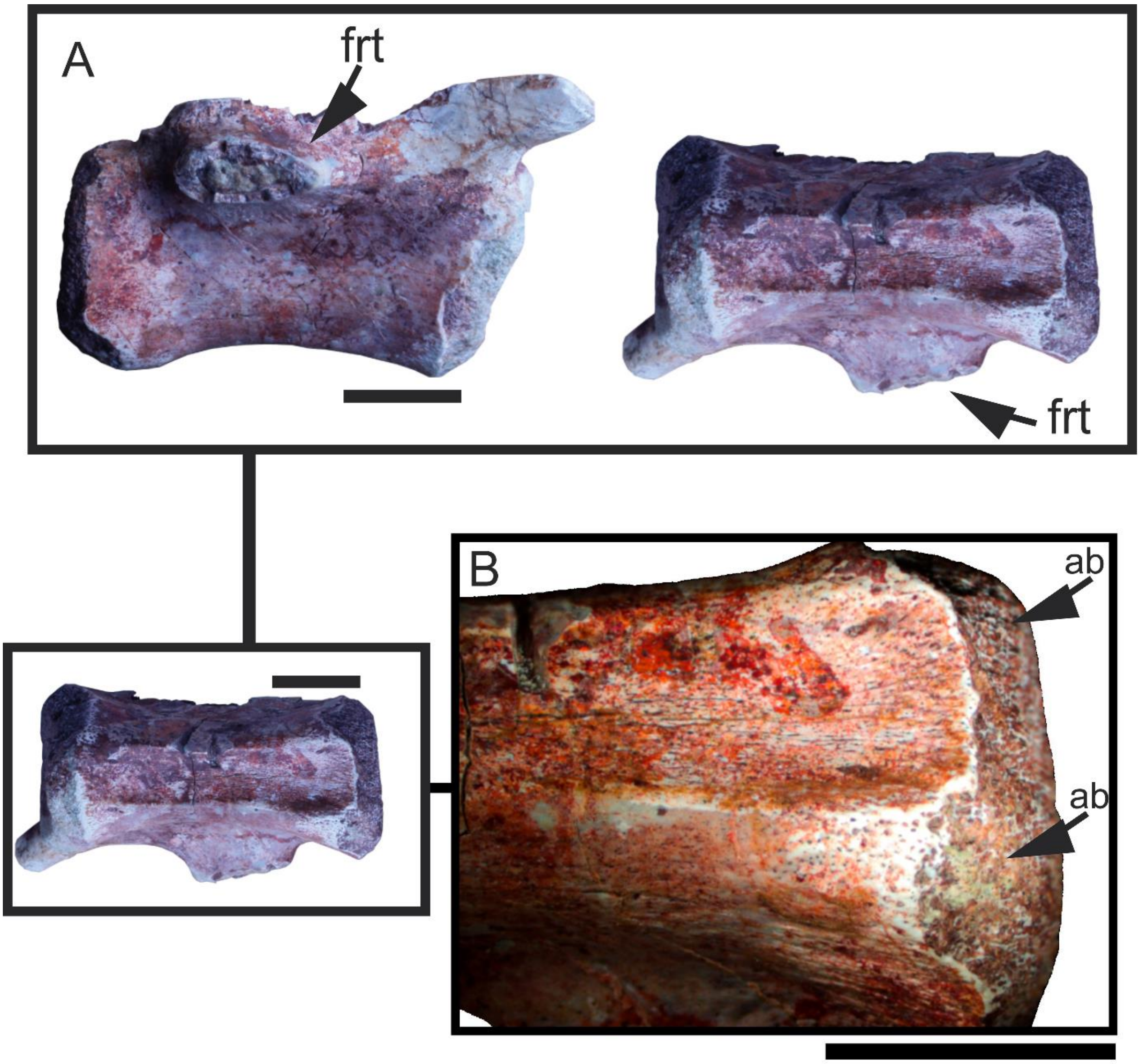


FIG. 11.—Coloration of teeth and vertebrae. **A-D**) theropod vertebra, scale 1 cm. **E-G**) aff. *Planohybodus* teeth, scale 0.5 cm. **H-I**) aff. *Planohybodus* teeth, scale 0.25 cm.

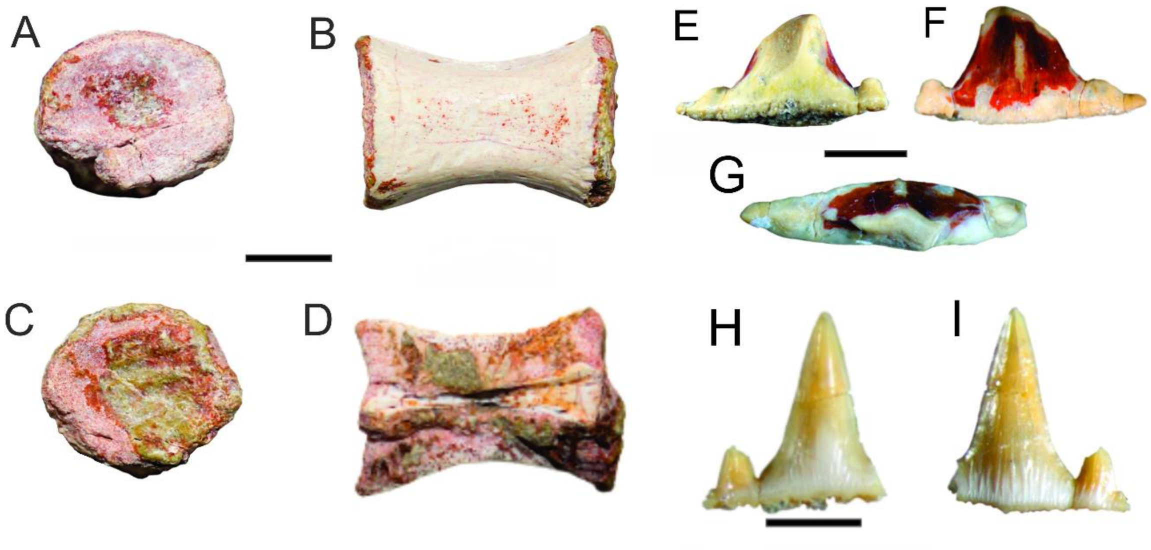


FIG. 12.—Taphonomic classes observed in the fossil assemblage of the Capianga Member. Scales: 1 cm.

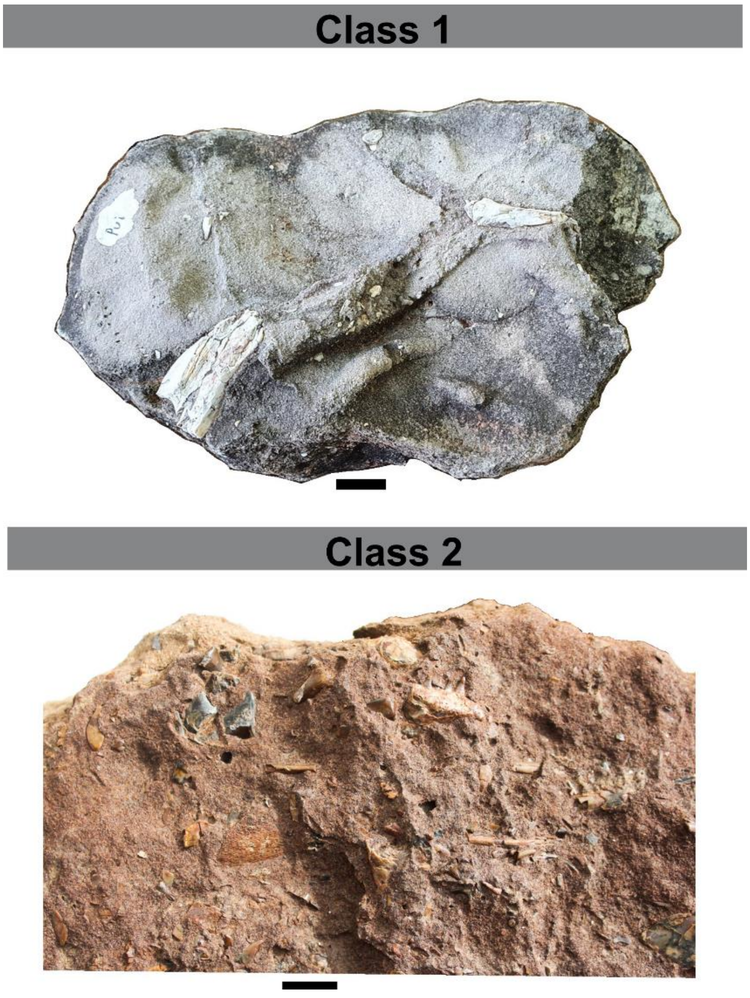


FIG. 13.—Taphonomic patterns observed in the Taphofacies A (TF-A). Scales: 2 cm.

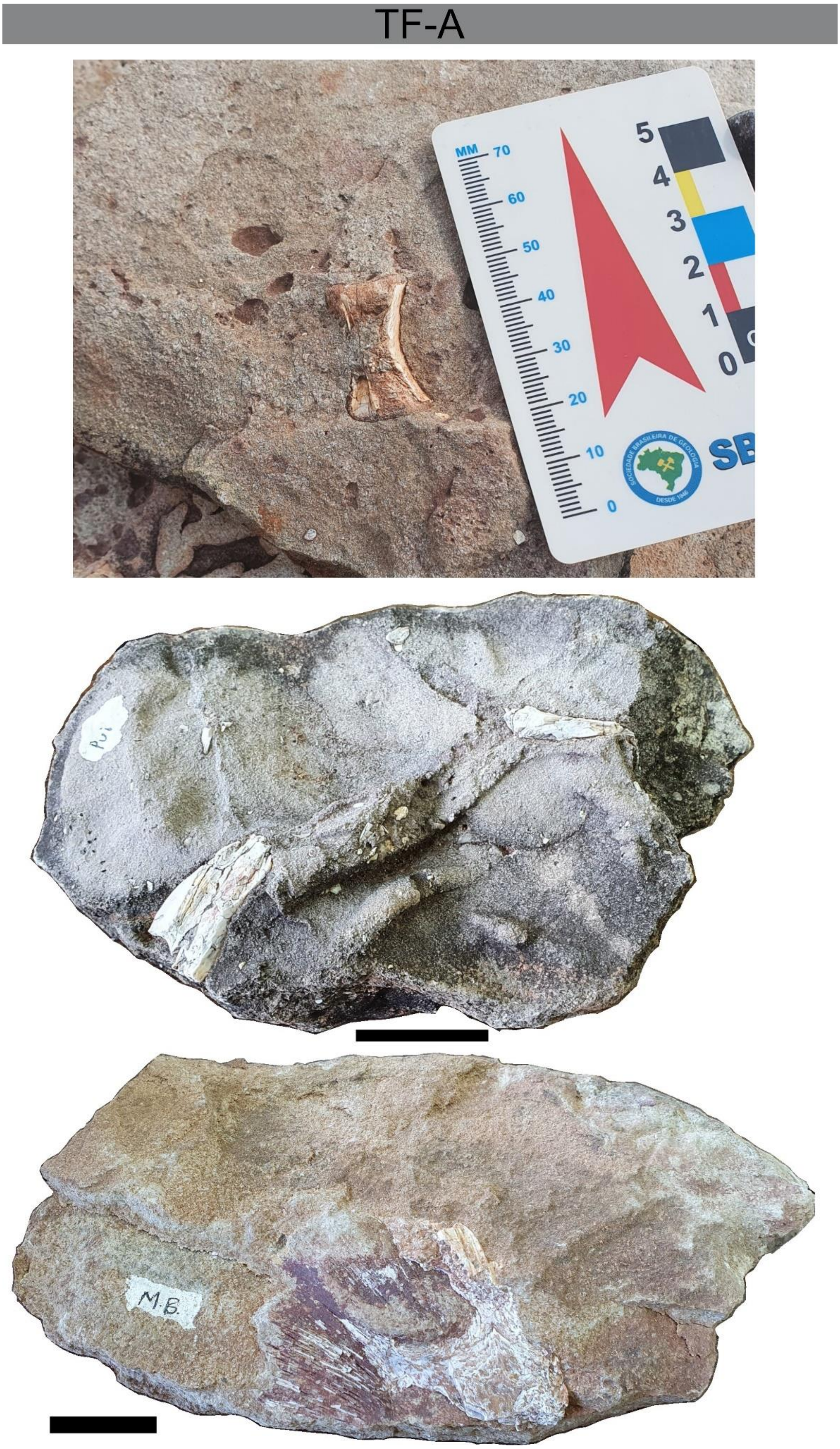


FIG. 14.—Taphonomic patterns observed in the Taphofacies B (TF-B). Scales: 2 cm.

FIG. 15.—Taphonomic patterns observed in the Taphofacies C (TF-C). Scales: 2 cm.

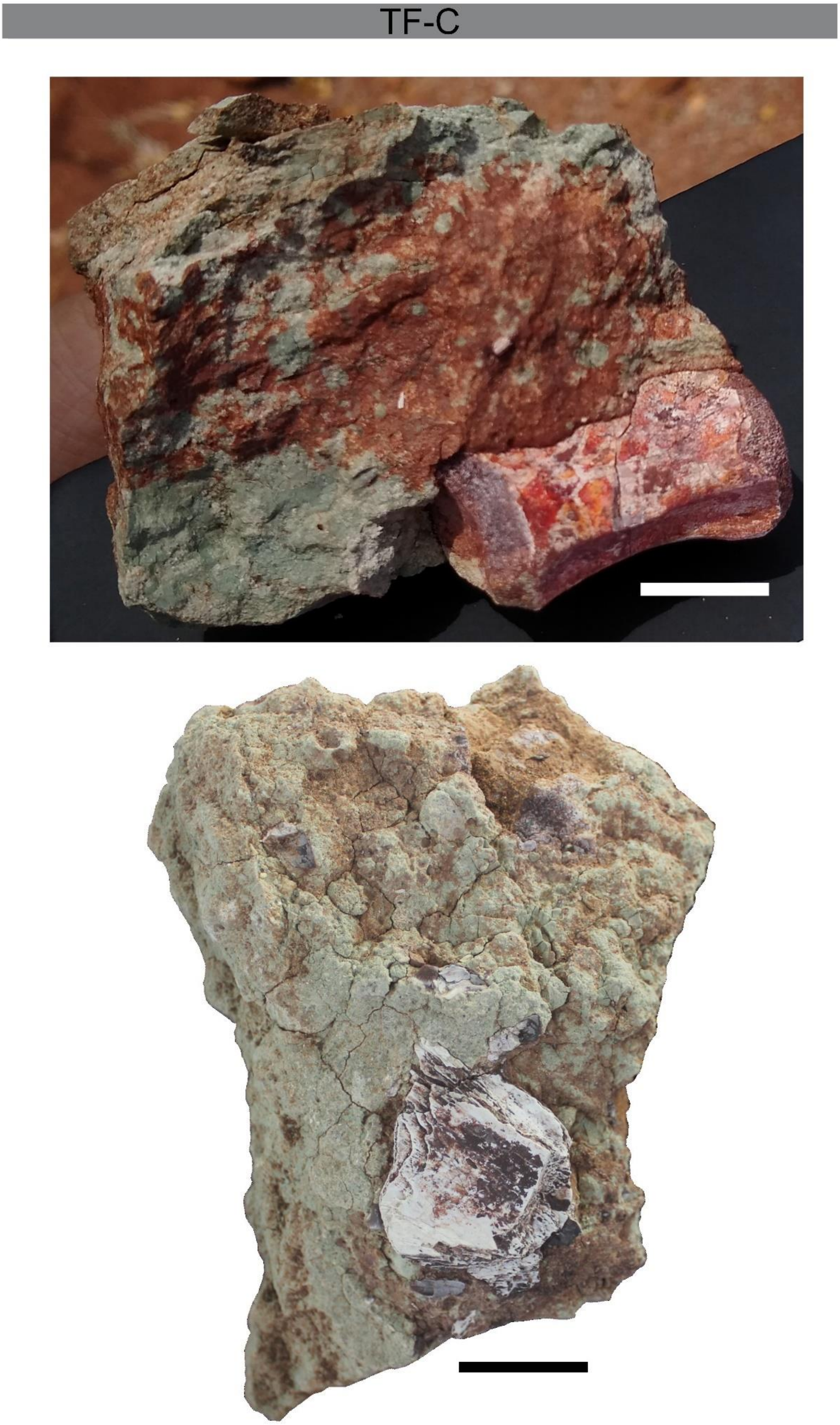


FIG. 16.—Middle caudal vertebra of the basal theropod Dilophosauridae found in TF-C (described in De Oliveira et al., 2022). Scales: 1 cm.

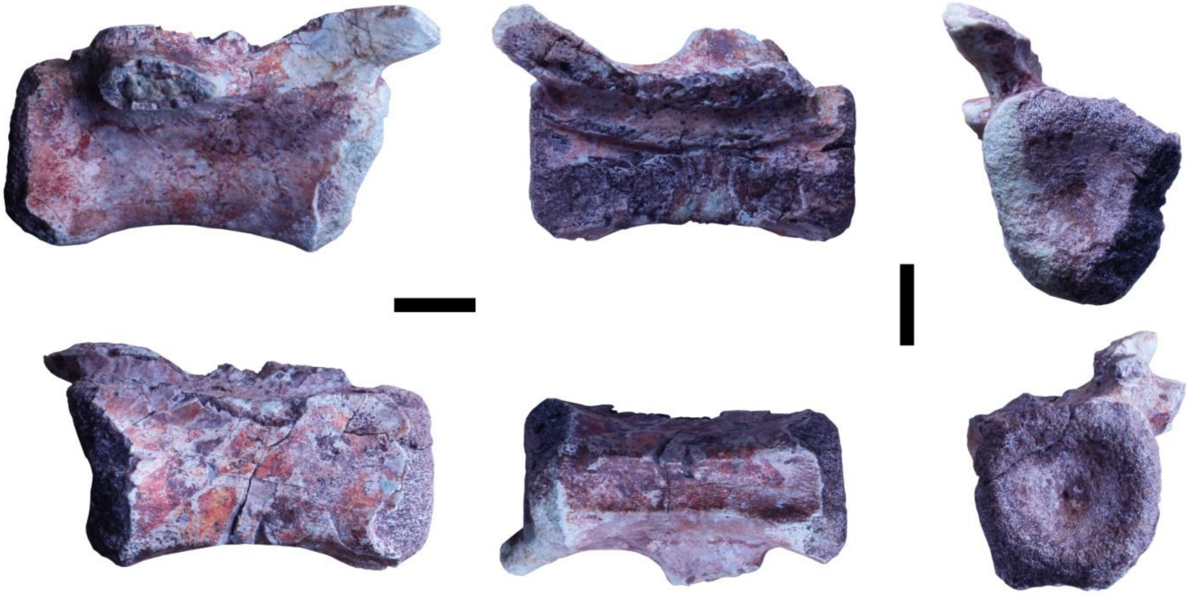


FIG. 17.—Lake System divided into Wave-dominated Lake Coast Environment and Distal Lake Environment.

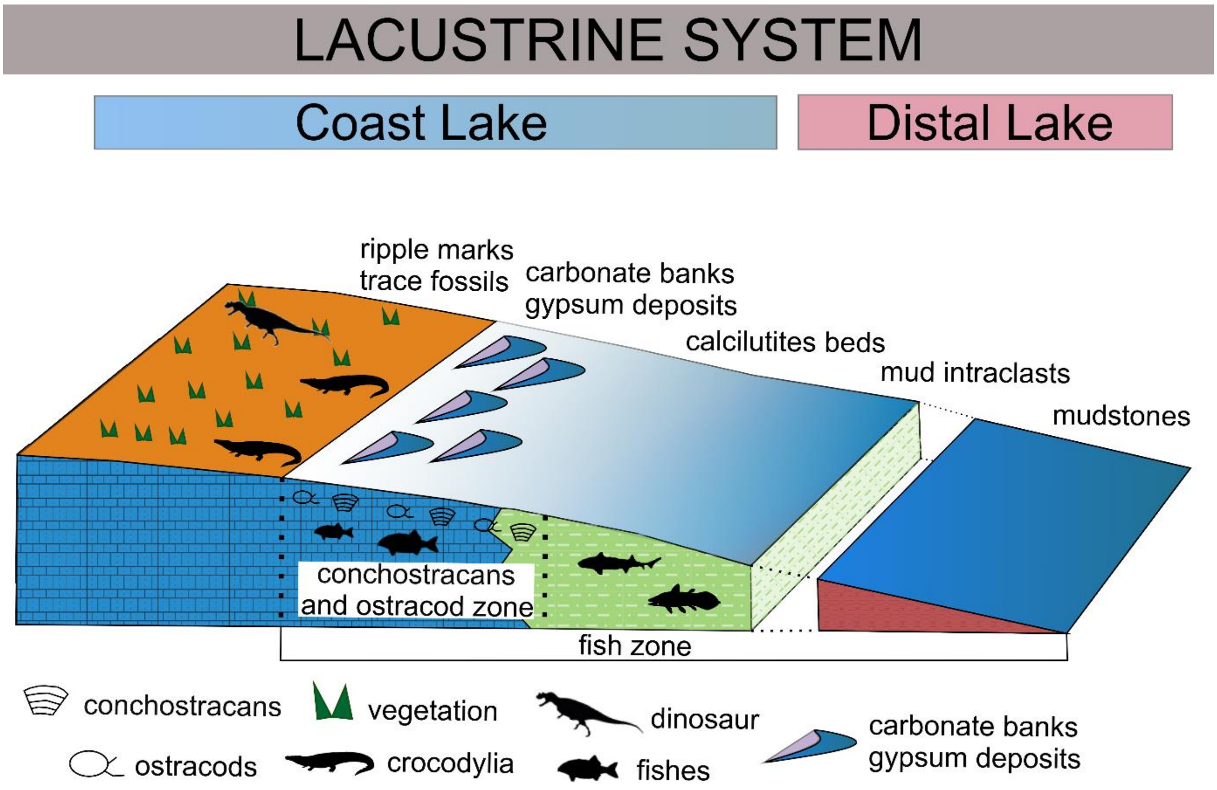
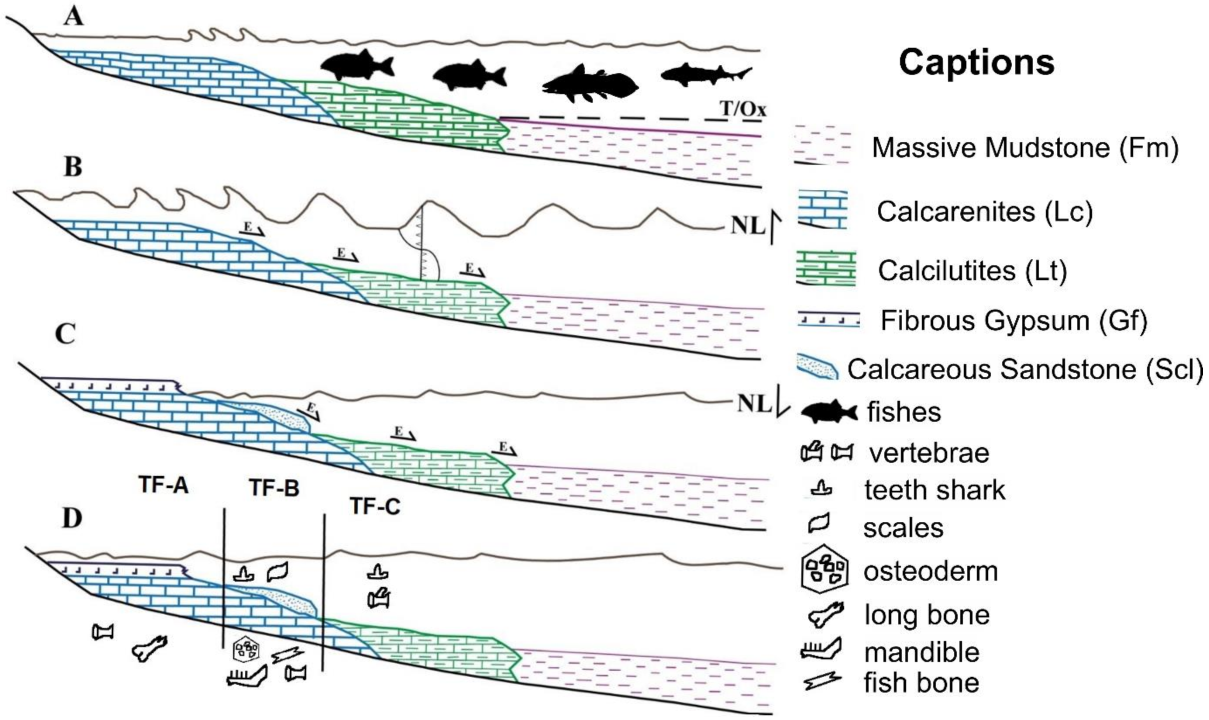


FIG. 18.—Taphonomic model integrating the interpreted taphofacies of the Capianga Member.



TABLES

TABLE 1.—Summary of the facies of the Capianga Member in the Jatobá Basin, including the lithofacies code, description, sedimentary structures and interpretation.

CODE	LITHOFACIES	DESCRIPTION AND SEDIMENTARY STRUCTURES	INTERPRETATION
Fm	Massive Mudstone	Massive reddish to purplish mudstones with mottled levels	Deposits formed under suspended load in subaqueous suspension fallout from muddy sheet floods in floodbasin under oxidizing conditions during and post-deposition (Abdul Aziz et al., 2003).
Fl	Laminated shales	Red, brown shales with millimetric horizontal lamination demarcated by interbedded brownish and whitish levels. Generally tabular, and rarely lenticular, centimetric thickness laminae. Shales have decimetric intercalations of greenish clay siltites with centimetric layers of reddish shales mottled with "limestone nodules" and fine calciferous sandstones.	Deposits originated under the action of subaqueous currents subaqueous in suspension fallout in predominant lower flow regime (Bohacs et al.., 2000; Abdul Aziz et al., 2003).
Lt	Calcilutites	Olive-gray laminated siltstones and fine sandstones, micaceous, with horizontal lamination. They occur in usually tabular, and rarely lenticular, layers of centimetric to decimetric thickness.	Deposits of subaqueous currents, predominantly under lower flow regime. Shallow lacustrine at top of upward shallowing sequence (Heermance et al., 2013).
Lc	Bioclastic Calcarenites	Layers of yellow to brown laminated limestones composed of ostracode shells. These limestones may feature wavy marks and desiccaction cracks at the top of the layers, climbing-ripples, horizontal lamination, and, more rarely, massive structure.	Deposits formed by suspension action in a low energy environment associated with intervals of subaerial exposure on the shore of the lacustrine environment, as a shallow-water, nearshore lacustrine deposit (Gore, 1989; Bohacs et al.., 2000).
Gf	Fibrous Gypsum	White gypsum (fibrous/prismatic gypsum), more common, and light dark gray (mosaic gypsum). Tabular and undulate lamination from millimeter to centimetric scale. May feature dolomudstone lenses on a millimetre scale.	Precipitation of evaporites in calm waters below the wave base. Seasonal variations in brine depth. In situ gypsum formed at low lake level. Capped by flooding surface during lake transgression (Heermance et al., 2013).

Scl	Fine calcareous sandstones, with cross-laminaton	White fine calcareous sandstones, with cross-laminaton is arranged in layers or intercalated levels in both mudstones and shales. These sandstones present as sedimentary structures ripple marks and mud cracks at the top of the layers, climbing-ripples cross-laminations, horizontal lamination and, more rarely, massive structure.	Deposits formed under suspension action in a low energy environment. Presence of subaerial exposure level and sedimentation pause

TABLE 2.—Table with type and number of specimens found in the Capianga Member, and their relative NISP and FTI numbers.

SKELETAL ELEMENTS	**%**	**NISP**	**FTI**
scales	32	40	-
teeth	20,8	26	-
vertebra	2,4	3	76,21
shark spines	1,6	2	-
humerus	0,8	1	57,77
femur	0,8	1	24,26
osteoderm	0,8	1	-
partial mandible	0,8	1	34,56
unidentified bones	49	50	-

TABLE 3.—Integration of the observed taphofacies with the lithofacies and the pre-burial period.

TAPHOFACIES	TAPHONOMIC CLASS	TAPHONOMIC CHARACTERISTICS	LITHOFACIES	PRE-BURIAL PERIOD
TF-A	Class 1: Isolated, small and medium-sized, incomplete to rarely complete bones and scales.	Fractured, abrasion marks.	Calcarenites (Lc)	Short to medium
TF-B	Class 2: small to medium-sized bones, osteoderms, teeth and isolated scales *(bonebeds*).	Fractured, abrasion marks.	Calcarenites (Lc)	Medium to long
TF-C	Class 2: isolated semi-complete bones and isolated teeth.	Few fractures, abrasion marks	Calcilutites (Lt)	Short

ARTIGO 2

The first dinosaur from the Late Jurassic Aliança Formation of northeastern Brazil, west Gondwana: a basal Neotheropoda and its paleobiogeographical significance

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EDISON VICENTE OLIVEIRA

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The first dinosaur from the Jurassic Aliança Formation of northeastern Brazil, west Gondwana: a basal Neotheropoda and its age and paleobiogeographical significance

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Abstract:

In South America, little is known about Jurassic dinosaurs, contrasting with the extensive record of the late Triassic and Cretaceous, mainly in a vast area corresponding to the northern half of South America (west Gondwana). Herein, we describe for the first time a theropod dinosaur recovered from the Aliança Formation of the Jatobá Basin, represented by a caudal vertebra. Compared with theropods from the Jurassic, the specimen from Brazil is closer related to the basal neotheropods such as *Dilophosaurus wetherilli*, from the early Jurassic of North America. Basal neotheropods exhibited a worldwide distribution during the early Jurassic period, as suggested by the record in North America, South Africa and Antarctica. Thus, the new record from the Brazil suggests the survival of the basal lineage represented by *Dilophosaurus* and close relatives during the Middle-Late Jurassic. The new fossil occurrence described here also enables a worldwide correlation, reinforcing a Jurassic rather than a Late Triassic age for the Aliança Formation, for which it is provisionally assigned a Middle-Late Jurassic age.

Key Words: caudal vertebra, taxonomy, Neotheropoda, Gondwana, paleobiogeography, South America.

1. Introduction

Jurassic theropod dinosaurs reported from the supercontinent of Gondwana are still very poorly known (Rauhut and Pol, 2021), mainly in the portion corresponding to northern South

America (west Gondwana), which has been considered a poorly sampled zone (Goodwin et al., 2019). Apart from the west Gondwana, theropods are known from the Upper Elliot Formation of South Africa (Yates, 2005), Tendaguru Formation of Tanzania (Rauhut, 2011), Kadsi Formation of Zimbabwe (Raat and McIntosh, 1987), Mugher Mudstone Formation of Ethiopia (Goodwin et al., 1999), Tiouaren Formation of Niger (Rauhut and López-Arbarello, 2009), all from Africa. Other theropod records include the Tacuarembó Formation of Uruguay (Perea et al., 2009; Soto et al., 2020a, b), Toqui Formation of Chile (Novas et al., 2015), Sergi Formation (Jatobá Basin, northeastern Brazil) (Bandeira et al., 2021) and Guará Formation (Paraná Basin, southern Brazil) (Scherer and Lavina, 2005; Dentzen-Dias et al., 2007, 2008; Francischini et al., 2015, 2018), Cañadón Asfalto and Cañadón Calcáreo formations of Argentina (Rauhut and Pol, 2017, 2019, 2021) and Hanson Formation of Antarctica (Smith et al., 2007).

In northeastern Brazil, dinosaurs are represented in Jurassic and Cretaceous faunas, with the record of the latter period being much more numerous, with several Cretaceous dinosaur taxa (including also ichnofossils) described for the Araripe (Carvalho et al., 2020; Sayão et al., 2020), Sousa-Uiraúna-Brejo das Freiras (Leonardi and Carvalho, 2007; Ghilardi et al., 2016), and São Luis-Grajaú (Parnaiba) basins (Bittencourt and Langer, 2011). In contrast, records of Jurassic dinosaurs in Brazil, as in the rest of the Southern Hemisphere, are quite rare. The first one includes a dinosaur ichnoassemblage composed of theropod, ornithopod, and sauropod tracks from the Late Jurassic Guará Formation (Paraná Basin, southern Brazil) (Dentzien-Dias et al., 2007, 2008; Francischini et al., 2015, 2018). From the Brejo Santo Formation (Araripe Basin), in the State of Ceará, an isolated vertebra was identified as Dinosauria indet. (Melo and Carvalho, 2017). More recently, a poorly preserved isolated vertebra assigned to Charcarodontosauria was also described (Bandeira et al., 2021). However, the material comes from an uncertain lithostratigraphic unit of the Jatobá Basin, in the locality of Petrolândia, State of Pernambuco (Bandeira et al., 2021) (Fig. 1A).

Among the potentially dinosaur-bearing units in the state of Pernambuco, the Araripe and Jatobá basins stand out (Naish et al., 2004; Bandeira et al., 2021). We have been conducting fieldwork in the Jatobá Basin, in the locality of Ibimirim, with geological and paleontological survey objectives. New stratigraphic and paleontological data for the Jurassic and Cretaceous of the Jatobá Basin have been reported in recent years, with new invertebrate and vertebrate fauna (Silva et al., 2010; Guzmán-González et al., 2016, 2020; Carvalho et al., 2021; Almeida-Lima et al., 2022). In new fieldwork, prospecting was concentrated in the locality of Macambira, in the municipality of Ibimirim, where the Aliança and Sergi formations outcrop

(Fig. 1C). In this locality, numerous vertebrate fossils were collected, including several remains of tetrapods. This paper describes an isolated caudal vertebra of a dinosaur for the first time for the Aliança Formation. The material is taxonomically identified and its age and paleobiogeographic significance discussed. We provide the first formal description of an isolated caudal vertebra of a dinosaur for the entire Aliança Formation in Recôncavo-Tucano-Jatobá rift system.

2. Geological setting

The Jatobá Basin belongs to the Recôncavo-Tucano-Jatobá Rift system, which is located in northeastern Brazil. In this basin, the early rift event (Late Jurassic-early Cretaceous) is related to the formation of the South Atlantic Ocean (Fambrini et al., 2010, 2019). The stratigraphic succession that represents the early rift phase is characterized by the Brotas Group, which is composed mostly of continental rocks comprised from the base to the top by the Aliança and Sergi formations (Viana et al., 1971; Pierini et al., 2010; Kuchle et al., 2011; Fambrini et al., 2019; Guzmán-González et al., 2020). The Brotas sedimentary succession is believed to be deposited during the Dom João local Stage/Tithonian Stage/Age (latest Jurassic) in the central and northern regions of Gondwana, covering northeastern Brazil and western Africa (Kuchle et al., 2011). The Aliança Formation consists of a succession of reddish claystone as well as shale and siltstone interbedded with limestone, sandy limestone, or calcarenites (Guzmán-González et al., 2020). In the Recôncavo and Tucano basins, State of Bahia, the Aliança Formation is subdivided into two members: Boipeba and Capianga (Caixeta et al., 1994; Costa et al., 2007; Magnavita et al., 2012). The lower member Boipeba is composed mainly of arkosic, fine- to medium-grained sandstone with well-developed crossbeds. Some sandstone bodies are conglomeratic and contain intraclasts of shales from underlying units. The Boipeba member is related to a fluvio-aeolian sedimentation. The upper member Capianga represents a lacustrine sedimentation in the Jatobá Basin (Costa et al., 2007; Fambrini et al., 2019), consisting of red, purple to maroon, silty micaceous shale and mudstone with scattered green spots. Thin white sandy or carbonated layers are repeated cyclically throughout the section. Near the base, lenses of light-gray arkosic sandstone, shale, and laminae of gypsum and anhydrite are present. Thin-bedded dense limestone and chert are also found. The upper part of the Capianga Member is characterized by a coarsening and thickening upward succession, defining a gradational contact with the Sergi Formation (Scherer et al., 2007). The presence of evaporites, chert and ephemeral fluvial systems are features very common in playa lake systems such as the Aliança Formation at Recôncavo Basin (Scherer et al., 2007) and

Jatobá Basin (Fambrini et al., 2016), and the correlative Brejo Santo Formation in Araripe Basin (Fambrini et al., 2013). According to Guzmán-González et al. (2020) the playa lake of the Capianga Member presents a stable hydrology with a positive balance between precipitation and evaporation.

In the locality of Macambira, Jatobá Basin, the Aliança Formation is represented only by the Capianga Member. This unit presents abundant remnants of nonmarine ostracods, sometimes forming decimetric intervals of pure bioclastite limestones (Guzmán-González et al., 2016, 2020). The pelites themselves contain carapaces of ostracods, which makes them commonly calciferous, and have typical forms of the Dom João local stage, discussed below. In addition, the Capianga Member is characterized by abundant fossil remains of vertebrates, including teeth and spines of freshwater sharks (hybodontiforms) gathered in layers of bonebeds, freshwater conchostracans, and isolated and disarticulated bones and cranial fragments of the large fish coelacanth *Mawsonia gigas*, tooth plate of the Dipnoi Ceratodontidae, scales of *Lepidotes*, osteoderms and vertebrae of Crocodylomorpha, and some plant remains (Derby, 1878, 1880; Silva et al., 2010, 2011; Carvalho et al., 2021).

In the locality of Macambira (Fig. 1C), numerous vertebrate fossils were collected including several remains of tetrapods (Fig. 2), which includes the theropod vertebra discussed below. According to its nonmarine ostracod content, the Aliança Formation corresponds to the local RT-001 biozone, Dom João Stage of the Recôncavo Basin (Viana and Van Hinte, 1966; Viana et al., 1971; Poropat and Colin, 2012; Guzmán-González et al., 2020; Mendes et al., 2020; Almeida-Lima et al., 2021), assigned to the Late Jurassic. The ostracode biostratigraphy corresponds to *Theriosynoecum pricei* biozone, which in the Aliança Formation is characterized by an association including *Theriosynoecum pricei*, *T. uninodosa*, *T. quadrinodosum, Reconcavona*? *jatobaensis,* and *Alicenula*? spp. (Guzmán-González et al., 2016, 2020).

Based on the biostratigraphy, we followed a Jurassic age rather than Late Triassic for the Capianga Member of the Aliança Formation, but extended the time span back into the Middle Jurassic, considering other evidences (e.g. sharks and bony fishes, radiometric data) (see below).

3. Material and methods

3.1. Repositories and institutional abbreviations

The specimen described here comes from the outcrops of the Aliança Formation, in the municipality of Ibimirim, close to the locality of Macambira (Fig. 1), and is housed in the collections of the Paleontology Laboratory (PALEOLAB) of the Department of Geology, from the Center of Technology and Geosciences of the Federal University of Pernambuco (DGEO-CTG-UFPE).

3.2. Anatomical abbreviations

ns, neural spine; prz, prezygapophysis; tp, transverse process; vg; ventral groove.

4. Results

4.1. Systematic palaeontology

Dinosauria Owen, 1842
Saurischia Seeley, 1887
Theropoda Marsh, 1881
Neotheropoda (Bakker, 1986)

Material. Incomplete middle caudal vertebra, DGEO-CTG-UFPE 8538 (Fig. 3).

Description. The specimen corresponds to an isolated caudal vertebra with the base of the right neural arch, proximal portions of the transverse processes, and the right prezygapophysis. Concerning the anatomy of the vertebra, the anteroposteriorly elongate proportions of the centrum body and the presence of transverse processes indicate that DGEO-CTG-UFPE 8538 is a middle caudal vertebra. Compared to the described caudal vertebrae sequence for *Dilophosaurus wetherilli* (Marsh and Rowe, 2020), DGEO-CTG-UFPE 8538 compares well with the 39th and 40th (12th caudal) vertebrae. Distal and proximal epiphyses show signs of abrasion (Fig. 4). The articular faces are amphicoelous, with the anterior about oval in outline and shallowly concave, while the posterior facet is sub-circular in outline and more deeply excavated. Both articular surfaces are wider dorsally.

The body of centrum is elongated, relatively low, and poorly arched ventrally in the lateral view. There is no evidence of the presence of vertebral pneumaticity (pleurocouels). In the dorsal view (Fig. 4A, B), the neural canal becomes narrower in the midline. The vertebra is only moderately constricted between the articular surfaces in the dorsal and ventral views. Therefore, in the ventral view (Fig. 4C, D), the centrum exhibits a weakly hourglass shape. In the lateral view (Fig. 4E, F), the outline of the broken transverse process is oblong, with the base indicating that it was mainly directed laterally and placed slightly posterior to the midlength of the centrum. The transverse process was probably horizontal and slightly posteriorly directed, as suggested by the small proximal portion preserved in the posterior view. The prezygapophysis is well developed, exhibiting a strong base, and protrudes upwards and forwards, running almost parallel to the dorsal margin of the vertebra, and projecting slightly beyond the anterior rim of the centrum. The prezygapophysis forms a ~30° angle with the dorsal surface of the centrum. In the ventral view, the vertebra has a very wide and long ventral groove that covers the entire ventral surface of the centrum, reaching the rim of the posterior articular facet, so that the ventral contour of this facet is slightly concave (Fig. 4C, D). The groove is delimited by straight and well-marked ridges.

5. Discussion

5.1. Comparison and systematic affinities

The dimensions of the specimen suggest that it belonged to a medium-sized dinosaur. The generalized condition of DGEO-CTG-UFPE 8538 (Figs. 5A) compares better with basal neotheropods (Fig. 5B; see below), differing from basal Ceratosauria (e.g. *Ilokesia* or Tetanurae (*Allosaurus*) (Figs. 5C, D). In relation to the theropod fossils described for Middle and Late Jurassic from the Gondwana, the specimen described here only superficially resembles the ventrally grooved caudal vertebrae of theropods assigned to Tetanurae or Ceratosauria (Figs. 5I-L), which have been recorded in at least five localities in the Southern Hemisphere (Fig. 6B). Ceratosaurid theropods have been reported for the Tacuarembó Formation in Uruguay, however, only through isolated teeth (Soto et al. 2020b). Below, we compare DGEO-CTG-UFPE 8538 with described caudal vertebrae specimens from Argentina, Tanzania, and Brazil (Sergi Formation), as well as with the Early Jurassic *Dilophosaurus wetherilli* from North America.

The literature describing theropods from the Late Jurassic of Africa includes several vertebrae comparable to DGEO-CTG-UFPE 8538, including the caudal vertebra MB R 2162 assigned to *Ceratosaurus*(?) *roechlingi* (a *nomem dubium* according to Rauhut, 2011) and to MB R 1938 of *Veterupristisaurus milneri*, both described for the Tendaguru Formation, Tanzania (Rauhut, 2011; Figs.5E, I, J). Comparisons with the African theropod vertebrae are as follows. DGEO-CTG-UFPE 8538 share with MB R 1938 the transverse process placed slightly posterior to the midlength of the centrum, and the presence of a ventral groove. However, DGEO-CTG-UFPE 8538 differs from MB R 1938 in having a much less arched ventral outline in the lateral view, the centrum poorly constricted between the articular ends, and a deeper and well-marked longitudinal ventral groove. The MB R 2162, which is more incomplete, exhibits a remarkable similarity to DGEO-CTG-UFPE 8538: both vertebrae share the presence of a broad and deep longitudinal ventral groove, which is bordered laterally by sharp ridges and occupies a major part (half) of the ventral surface. Rauhut (2011) discusses this feature in detail, noting that the presence of a ventral groove, originally interpreted as a synapomorphy of Ceratosauria (Rowe and Gauthier, 1990; Tykosky and Rowe, 2004) has a much wider distribution in theropods, although there is substantial variation in this character. According to Rauhut (2011), this character state is widespread in basal theropods and cannot constitute a synapomorphy of Ceratosauria. This feature optimizes as a general character state in basal theropods on those tree topologies that advocate a position of ‘dilophosaurs’ and neoceratosaurs as subsequently closer outgroups to Tetanurae (Rauhut, 2011). In short, we ruled out relationships of DGEO-CTG-UFPE 8538 with Averostra, particularly with tetanurans and ceratosaurians, considering the absence of derived characters from this group in the Brazilian material (see e.g. Coria and Salgado, 1998; Pol and Rauhut, 2012; Bandeira et al., 2021).

For Argentina, the literature reports caudal vertebrae for the Cañadón Asfalto Basin of the Chubut Province, with records for two units: Cañadón Asfalto (early Middle Jurassic) and Cañadón Calcáreo (Late Jurassic) formations. In comparison with the caudal vertebra of *Condorraptor currumili* (Tetanurae; Fig. 5K) from the Cañadón Asfalto Formation (Rauhut, 2005), DGEO-CTG-UFPE 8538 shares with this species an elongated centrum, transverse processes that are mainly laterally and slightly posteriorly oriented, and the presence of a longitudinal ventral groove. In contrast, DGEO-CTG-UFPE 8538 has a much broader (at least twice as wide) and longer longitudinal groove as well as the lower vertebra body than *C. currumili*. Compared to with the caudal vertebra described for *Pandoravenator fernandezorum* (Tetanurae) from the Cañadón Calcáreo Formation, Argentina (Rauhut and Pol, 2017), DGEO-CTG-UFPE 8538 resembles this species by the elongated body of the centrum and by the more anteriorly than dorsally inclined prezygapophyses. However, DGEO-CTG-UFPE 8538 differs from that species in that the centrum is hexagonal in outline and the posterior end of the centrum extends slightly further ventrally than the anterior end to form the chevron facets. Despite the similarities mentioned above, DGEO-CTG-UFPE 8538 lacks the strongly elongated prezygapophysis observed in tetanurans (Rauhut, 2011), which rules out a closer relationship with theropods of this group. More recently, another caudal vertebra associated with other skeletal remains from the Cañadón Asfalto Formation was described by Rauhut and Pol (2021), and tentatively assigned to Abelisauridae (Ceratosauria). The material, however, is extremely fragmentary, providing few diagnostic features, and was identified as a distal caudal vertebra while DGEO-CTG-UFPE 8538 is a middle caudal vertebra. However, for a non-illustrated specimen, is reported the presence of a “very slightly developed, broad longitudinal groove ventrally” (Rauhut and Pol, 2021), which resembles in this feature the specimen described here. However, DGEO-CTG-UFPE 8538 lacks derived features of ceratosaurian abelisaurids such as the position of the transverse process along the anteroposterior axis of the neural arch that varies, being located in the middle or in the posterior half of the vertebra, and the prezygapophysis is straight and anterodorsally oriented (Méndez, 2014).

When compared to the Carcharodontosauria (Allosauroidea) material described for the Sergi Formation, Brazil (Bandeira et al., 2021; Figs. 5F, L), DGEO-CTG-UFPE 8538 differs from it in at least three features: vertebra weakly constricted between the ends (or less hourglass-like), longer longitudinal groove, broader and bordered laterally by sharp ridges, and the anterior articular surfaces sub-triangular instead of sub-circular. Both compared vertebrae are similar in size; however, the Sergi Formation specimen preserved only the centrum, preventing a more detailed comparison. It is not clear from the illustrations whether the longitudinal ventral groove and "ventral keels" are preserved (Bandeira et al., 2021). Pending better-preserved materials in the Sergi Formation, we discarded close phylogenetic relationships between both specimens.

DGEO-CTG-UFPE 8538 displays a set of plesiomorphic features present in Triassic and Early Jurassic taxa (e.g. elongated centrum, poorly anteriorly expanded prezygapophysis, and presence of longitudinal ventral groove). The centrum has a length 1.9 times their height (ratio of length 38.4 x anterior height 20.2 mm equal 3.2), similar to that of many middle caudal vertebrae of Triassic and Early Jurassic taxa (see e.g. Pretto et al., 2015; Nesbitt et al., 2019; Marsh and Rowe, 2020), which the ratios ranges from 1.94 to 2.9. However, the general anatomy of DGEO-CTG-UFPE 8538 compares well with the caudal vertebrae of the basal neotheropod *Dilophosaurus wetherilli* (Figs. 5B, H), from the Early Jurassic of North America (Marsh and Rowe, 2020). These similarities include a character combination of an elongated caudal centrum body, morphology and extension of the prezygapophysis, presence of a pronounced longitudinal ventral groove, transverse processes positioned slightly posterior to the midlength of the centrum, and the anterior articular face about oval in outline and the posterior facet sub-circular in outline. DGEO-CTG-UFPE 8538 and *Dilophosaurus* share a similar length x anterior height centrum ratio (1.9 DGEO-CTG-UFPE 8538 and 2.0 in *Dilophosaurus*), but DGEO-CTG-UFPE 8538 exhibits a stronger transverse process. Current basal theropod phylogenies have recovered two well supported nodes such as Neotheropoda and Averostra (Yates, 2005; Marsh and Rowe, 2020). In turn, Neotheropoda is composed by a clade that encompass Coelophysoidea and the clade Dilophosauridae (Hendrickx et al., 2015; Rauhut and Pol, 2021). However, Marsh and Rowe (2020) no recover a monophyletic Dilophosauridae. From a Gondwana perspective (Fig. 6A), it is interesting to note that *Dracovenator*, an Early Jurassic neotheropod from South Africa, has been recovered as a closer outgroup to it or even the sister taxon to *Dilophosaurus* (Yates, 2005; Rauhut and Pol, 2021). Assuming the probable phylogenetic relationship between DGEO-CTG-UFPE 8538 and *Dilophosaurus*, the presence of a basal neotheropod in the Aliança Formation constitutes a very interesting taxonomic and temporal data for the evolution of the basal neotheropod faunas (see below). Unfortunately, the material studied is scarce, but it opens new perspectives for future discoveries of basal neotheropods in the Jurassic of northern South America.

5.2. Age of the Aliança Formation and paleobiogeography

The Aliança Formation has been considered Late Jurassic for several decades (Viana and Van Hinte, 1966; Schaller, 1969; Viana et al., 1971; Da Rosa and Garcia, 2000; Guzmán-González et al., 2016; Almeida-Lima et al., 2022), but recent geochronological studies have indicated an older age for this unit (e.g. Thomaz-Filho and Lima, 1981; Silva et al., 2012). Traditionally, the presence of typical Jurassic invertebrate and vertebrate (mainly fishes) taxa (see below), as well as non-marine ostracods, together with comparisons to the related lithostratigraphic units, suggested a Late Jurassic/Thitonian age. However, published radiometric dates extend the age of the Aliança Formation back into the Late Triassic (see below), greatly contradict the biostratigraphic schemes. The first published absolute age for the lower part of the Aliança Formation resulted in an age at 165 ± 15 Ma (Thomaz Filho and Lima, 1981), indicating a late Early-Late Jurassic age for this unit. Although very undefined, this interval is not considered by us to be improbable, considering some vertebrate taxa such as aff. *Planohybodus* sp. and *Mawsonia* (Fig. 7) with first occurrences in the Middle Jurassic (Bathonian). Another radiometric dating applied to the Aliança Formation was performed by Silva et al. (2012) using Rb/Sr whole-rock isochron method in clay minerals, indicating an original depositional age assigned to the Late Triassic for the Aliança Formation (226 ± 6 Ma.). Silva et al. (2012) also dated the rift phase Itaparica Formation, with results at 224 ± 32 Ma. Although those authors recognize the great imprecision (estimate error) of this age (± 32 Ma) due to the fact that clay minerals may still be recording the source area of the sediment, and not necessarily the original depositional age of the sedimentary rock, they sustain that the Aliança Formation is Late Triassic. On the basis of the same method, the Bananeira Formation from the Sergipe-Alagoas Basin, a correlative unit to that of the Aliança Formation, was dated at 227.2 ± 2.2 Ma (Silva et al., 2006). To support your isotopic data, Silva et al. (2012) argue that equivalent units in the Gabon Basin were dated as Middle Jurassic by palynology (Arai et al., 1989), and the endemic nature of non-marine ostracods, upon which the main biostratigraphic scheme of the Recôncavo Series is based, does not allow significant progress other than that already achieved with correlation with reference sections. We agree with the endemic character of ostracods, but the palynology data indicate an age within the Jurassic and not the Triassic.

In view of the current paleofaunistic knowledge of the Aliança Formation we see a Late Triassic age for this unit as not plausible. Stratigraphic relationships with other units indicate that upper part of the Aliança Formation contact with the Sergi Formation, and both units have contact unconformable with lower Cretaceous units such as the Candeias Formation, in the Jatobá Basin (Fambrini et al., 2019). On the other hand, the lower contact of the Aliança Formation does not establish an age limit, since this unit is deposited on the marine devonian rocks (Inajá Formation).

Figure 7 shows a comparison of different ages and fossils source. The well-represented genus *Theriosynoecum* in the Aliança Formation has a stratigraphic range from the Middle Jurassic (Upper Bajocian?- Bathonian) to Early Cretaceous (middle? Albian), questionably Late Cretaceous (Cenomanian) (Sames, 2016). As see above, aff. *Planohybodus* sp. suggests a range from Bathonian (Middle Jurassic) to Berriasian (Early Cretaceous). The species *Planohybodus marki*, previously referred for the Aliança Formation (Silva et al., 2011), is a *nomem dubium* (Stumpf et al., 2021). Other evidence comes from microfossils. In this respect, the most used biochronological scheme is based on the ostracod taxa which defined the *Theriosynoecum pricei* biozone, commonly assigned to the Late Jurassic (Viana et al., 1971; Poropat and Colin, 2012; Guzmán-González et al., 2016, 2020; Carvalho et al. 2021; Almeida-Lima et al., 2022). Another important dating source includes palynological data of related units assigned to Late Jurassic such as the Missão Velha Formation of the Araripe Basin (Coimbra et al., 2002) and the M'Vone Formation of the Gabon Basin (Da Rosa and Garcia, 2000; Mounguengui et al., 2002, 2008). Although they are abundant in the Aliança Formation, ichnofossils has not been studied. Preliminary identification of these lacustrine trace fossils, such as Spongeliomorpha, from the nonmarine *Scoyenia* ichnofacies (Buatois and Mángano, 1995, 1998; Buatois et al. 1996; Melchor et al. 2006, 2009), suggest a Early to Late Jurassic age (Sinemurian-Tithonian range) (e.g. Fürsich, 1973; Melchor et al. 2006). Concerning the dinosaur described here, its basal condition regarding avesrostrans raises an important question about the Late Jurassic age currently considered for the Aliança Formation. Our comparative studies point to a morphological condition that best compares to the late Triassic and Early Jurassic taxa. As seen above, among these taxa, a greater combination of characters is shared between DGEO-CTG-UFPE 8538 and *Dilophosaurus*, from the Early Jurassic of North America. Thus, we assume that DGEO-CTG-UFPE 8538 constitutes a conservative (plesiomorphic) morphology surviving post-early Jurassic in east Gondwana. Coupled with the other evidences (first stratigraphic occurrence of some genera, Fig. 7), we suggest moving back the age of the Aliança Formation into the Middle Jurassic, then assigning a Middle-Late Jurassic age span to this unit. Comparing the record of the basal neotheropod in the Aliança Formation with those of theropods reported for the Middle and Late Jurassic from South America, we note two marked differences: (1) only Averostra (Tetanurae and Ceratosauria) are reported for the known faunas on the basis of osteological/teeth evidence (Rauhut and Pol 2017; Rauhut and Pol 2021; Soto and Perea 2008; Soto et al. 2020a, b); and (2) the ichnological record of the Guará Formation is composed by quadrupedal tracks (ankylosaurian), closely related to those described for the early Cretaceous ichnotaxa (Francischini et al., 2018) and a large theropod (Dentzien-Dias et al., 2007). Finally, the presence of a basal neotheropod in the Early Jurassic of South Africa (Yates, 2005), and now in the Middle-Late Jurassic of northern South America, both related to *Dilophosaurus* from North America, expands the taxonomic and paleobiogeographic data, strengthening the presence of these basal dinosaurs in the Gondwana. Basal neotheropods exhibited a worldwide distribution during the Early Jurassic period, as suggested by the records in North America, South Africa and Antarctica (Smith et al., 2007). Thus, the new record from the Brazil suggests the survival of the basal lineage represented by *Dilophosaurus* and close relatives during the Middle-Late Jurassic from the west Gondwana.

6. Conclusions

The fossil described here represents the first dinosaur for the Aliança Formation fauna, a Jurassic assemblage previously represented by hybodontiforms and bone fishes, basal crocodylomorphs, and microfossils. This record represents the second theropod dinosaur from the Jurassic of the Jatobá Basin, taking into account a recently published theropod for the Sergi Formation.

The Jurassic Brazilian vertebrae compares well with the caudal vertebrae of the basal theropod *Dilophosaurus wetherilli* (Neotheropoda), from the Early Jurassic of North America, including a character combination of an elongated caudal centrum body, morphology and extension of the prezygapophysis, presence of a pronounced longitudinal ventral groove, transverse processes positioned slightly posterior to the midlength of the centrum, and the anterior articular face about oval in outline and the posterior facet sub-circular in outline.

Basal neotheropods exhibited a worldwide distribution during the Early Jurassic period, as suggested by the records in North America, South Africa and Antarctica. Thus, the new record from the Brazil suggests the survival of the basal lineage represented by *Dilophosaurus* and close relatives during the Middle-Late Jurassic.

A review of the previously published stratigraphic and biostratigraphic data of the Aliança Formation no support the currently accepted Late Jurassic (Tithonian) age. However a Late Triassic age as suggested by radiometric ages is unlikely. The new fossil evidence described here, constitutes a world-wide correlation fossil, reinforcing a Jurassic rather than a Late Triassic age for the Aliança Formation. Coupled with the other faunistic evidences, we suggest moving back the age of the Aliança Formation into the Middle Jurassic, then assigning a Middle-Late Jurassic age span to this unit. New stratigraphic and faunistic data are needed to confirm or modify this new assessment.

Author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the journal of South American Earth Sciences.

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Declaration of competing interest

There are no conflicts of interest in this paper/project.

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References

Almeida-Lima, D. S., Piovesan, E. K., Guzmán, J., de Melo Mendes, D. and Neumann, V. H. D. M. L. 2022. Non-marine ostracods from the Late Jurassic–Early Cretaceous of Araripe, Jatobá and Tucano Norte basins, northeast Brazil Ostracodes non marins Jurassique Superieur–Cretace Inferieur des bassins d'Araripe, Jatobá et Tucano Norte, nord-est Bresil. *Revue de Micropaléontologie*, *74,* 100605

Arai, M., Hashimoto, A.T., Uesugui, N., 1989. Signifificado cronoestratigráfifico da associação microflorística do Cretáceo Inferior do Brasil. Boletim de Geociências da Petrobras 3 (1), 87e103.

Bandeira, K.L.N., Brum, A.S., Pêgas, R.V., Souza, L.G., Pereira, P.V.L.G.C. and Pinheiro, A.E.P. 2021. The first Jurassic theropod from Sergi Formation, Jatobá Basin, Brazil. *Anais da Academia Brasileira de Ciências,* **93**, e20201557.

Bittencourt, J.S. and Langer, M.C. 2011. Mesozoic dinosaurs from Brazil and their biogeographic implications. *Anais da Academia Brasileira de Ciências*, **83**, 23-60.

Buatois, L.A., and Mángano, M.G.,1995. The paleoenvironmental and paleoecological significance of the lacustrine *Mermia* ichnofacies: an archetypical subaqueous nonmarine trace fossil assemblage. *Ichnos,* **4**:151–161.

Buatois, L.A., and Mángano, M.G. 1998. Trace fossil analysis of lacustrine facies and basins. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **140**: 367-38.

Buatois, L.A., Mángano, M.G. and Aceñolaza, F.G. 1996. Icnofaunas paleozoicas en sustratos firmes no marinos: evidencias del Pérmico de la cuenca Paganzo. *Ameghiniana,* **33**: 265–270.

Caixeta, J. M., Bueno, G. V., Magnavita, L. P. and Feijó, F. J. 1994. Bacias do Recôncavo, Tucano e Jatobá. *Boletim de Geociências da Petrobrás*, **8**: 163–172.

Coria, R.A. and Salgado, L. 1998. A basal Abelisauria, Novas 1992 (Theropoda-Ceratosauria) from the Cretaceous of Patagonia, Argentina. Gaia, 15, 89-102.

Carvalho, A.R.A., Oliveira, G.R. and Barreto, A.M.F. 2021. New Crocodylomorpha remains from the late jurassic Aliança Formation (Dom João stage), Jatobá Basin. Journal of South Americn Earth Sciences, **109**:103256.

Carvalho, I.S., Leonardi, G., Rios-Netto, A.M., Borghi, L., Freitas, A.P., Andrade, J.A. and Freitas, F.I. 2020. Dinosaur trampling from the Aptian of Araripe Basin, NE Brazil, as tools for paleoenvironmental interpretation. *Cretaceous Research*, **117**: 1-14.

Coimbra, J. C., Arai, M., and Carreño, A. L. 2002. Biostratigraphy of Lower Cretaceous microfossils from the Araripe basin, northeastern Brazil. *Geobios*, *35*(6), 687-698.

Costa, I.P., Bueno, G.V., Milhomem, P.S., Silva, H.S.L.E., Kosin, M.D. 2007. Sub-bacia de Tucano Norte e Bacia de Jatobá. Boletim de Geociências da Petrobras, **2**: 445-453. (Boletim 15).

Da Rosa, A.A.S. and Garcia, A.J.V. 2000. Palaeobiogeographic aspects of northeast Brazilian basins during the Berriasian before the break up of Gondwana. *Cretaceous Research*, v21, 211-239.

Dentzien–Dias, P. C., Schultz, C. L., Scherer, C. M. S., and Lavina, E. L. C. 2007. The trace fossil record from the Guará Formation (Upper Jurassic?), southern Brazil. Arquivos do Museu Nacional, 65, 585–600.

Dentzien-Dias, P.C., Schultz, C.L. and Bertoni-Machado, C., 2008. Taphonomy and paleoecology inferences of vertebrate ichnofossils from Guará Formation (Upper Jurassic), southern Brazil. J. S. Am. Earth Sci. 25, 196-202.

Derby, O.A. 1878. Contribuições para o estudo da geologia do Valle do rio São Francisco. Archivos do Museu Nacional, **4**: 119.

Derby, O.A. 1880. Geology of the rio São Francisco, Brazil. Ameriac Journal Science, **19**: 236.

Fambrini, G.L., Neumann, V.H.M.L., Barros, C.L., Agostinho, S.M.O., Galm, P.C. and Menezes-Filho, J.A.B. 2013. Análise estratigráfica da Formação Brejo Santo, Bacia do Araripe, Nordeste do Brasil: implicações paleogeográicas. *Geol. USP, Série Científica*, **13** (4), 3-28.

Fambrini, G.L., Neumann, V.H.M.L., Guzmán-González, J., Oliveira, E.V., Piovesan, E.K. and Sial, A.N. 2016. Sequência de Início de Rifte (Grupo Brotas) da Bacia de Jatobá: resultados preliminares. In: Congresso Brasileiro de Geologia, 48, 2016, Porto Alegre - RS. *Anais*, v. único. Meio digital.

Fambrini, G.L., Rocha, D.E.G.A., Oliveira, É.V., Jesuíno, P.S.L., Menezes-Filho, J.A.B., Queiroz, R.G.B. and Neumann, V.H.L.M. 2019. Análise faciológica e deposicional dos depósitos flúvio-eólicos da Formação São Sebastião (Eocretáceo), região de Campos-Ibimirim, Bacia de Jatobá, PE, nordeste do Brasil. *Geociências,* **38**, 1-31.

Fambrini, G.L., Neumann, V.H.M.L., Lemos, D.R., Araújo, J.T., Lima-Filho, M.F. and Silva-Filho, W.F. 2010. Stratigraphy and sedimentology of the Rift Initiation to Rift Climax stages of the Araripe Basin, Northeastern Brazil: new considerations. In *International Sedimentology Congress*, 18., Abstracts Volume. pp. 333. IAS/PETROBRAS, Mendoza, Argentina. CD-ROM.

Francischini, H., Dentzien-Dias, P.C., Fernandes, M.A. and Schultz, C.L. 2015. Dinosaur ichnofauna of the upper Jurassic/lower Cretaceous of the Paraná Basin (Brazil and Uruguay). *Journal of South American Earth Sciences*, 6**3**, 180-190.

Francischini, H., Sales, M. A., Dentzien–Dias, P., & Schultz, C. L. 2018. The presence of ankylosaur tracks in the Guará formation (Brazil) and remarks on the spatial and temporal distribution of late Jurassic dinosaurs. *Ichnos*, *25*(2-3), 177-191.

Fürsich, F.T. 1973. A revision of the trace fossils Spongeliomorpha, Ophiomorpha and Thalassinoides. *Neues Jahrbuch für Geologie und Paläontologie*, Monatshefte, 719–735.

Ghilardi, A.M., Aureliano, T., Duque, R.R.C., Fernandes, M.A., Barreto, A.M.F. and Chinsamy, A., 2016. A new titanosaur from the Lower Cretaceous of Brazil. Cretac. Res. 67, 16e24.

Goodwin, M.B., Clemens, W.A., Hutchinson, J.H., Wood, C.B., Zavada, M.S., Kemp, A., Duffin, C.J. and Schaff, C.R. 1999. Mesozoic continental vertebrates with associated palynostratigraphic dates from the northwestern Ethiopian Plateau. *Journal of Vertebrate Paleontology*, **19**(4): 728-741.

Goodwin, M.B., Irmis, R.B., Wilson, G.P., De Mar Jr., D.G., Melstron, K., Rasmussen, C., Atnafu, B., Alemu, T., Alemayheu, M. and Chernet, S.G. 2019. The first confirmed sauropod dinosaur from Ethiopia discovered in the Upper Jurassic Mugher Mudstone. *Journal of South American Earth Sciences*, **159**, 103571.

Guzmán-González, J., Fambrini, G.L., Oliveira, E. V. and Usma, C. 2015. Estratigrafia da Bacia de Jatobá: estado da arte. *Estudos Geológicos*, **25**:53–76.

Guzmán-González, J., Piovesan, E.K., Fambrini, G.L. and Oliveira, E.V. 2016. Non-marine ostracoda from the Aliança Formation in the north-central portion of the Jatobá Basin, northeastern Brazil. *Revista Brasileira de Paleontologia*, **19**, 15–24.

Guzmán-González, J., Sial, A. N., Piovesan, E. K., Oliveira, É.V. and Fambrini, G.L. 2020. Paleolimnological reconstruction of a marginal area of Jurassic Capianga Lake, Jatobá Basin, northeast Brazil. *Journal of Paleolimnology*, **63**, 113-128.

Hendrickx, C., Hartman, S.A. and Mateus, O. 2015. An overview of non-avian Theropod discoveries and classification. *PalArch's Journal of Vertebrate Palaeontology*, **12**, 1-73.

Kuchle, J., Scherer, C.M.D.S., Born, C.C., Alvarenga, R.D.S. and Adegas, F. 2011. A contribution to regional stratigraphic correlations of the Afro-Brazilian depression - The Dom João Stage (Brotas Group and equivalent units - Late Jurassic) in Northeastern Brazilian sedimentary basins. *Journal of South American Earth Sciences*, **31**, 358–371.

Leonardi, G. and Carvalho, I.S. 2007. Dinosaur ichnocoenosis from Sousa and Uiraúna-Brejo das Freiras basins, Northeast of Brazil. 355-369. *In* Carvalho, I.S., Cassab, R.C.T., Schwanke, C., Carvalho, M.A., Fernandes, A.C.S., Rodrigues, M.A.C., Carvalho, M.S.S., Arai, M. and Oliveira, M.E.Q. (eds) *Paleontologia: Cenários de Vida*. Rio de Janeiro, Interciência.

Magnavita, L.P., Szatmari, P., Cupertino, J.A., Destro, N. and Roberts, D.G. 2012. The Recôncavo Basin. In David, G., Roberts, D.G., Bally, A.W. (eds.) Regional Geology and Tectonics: Phanerozoic Rift Systems and Sedimentary Basins. Amsterdam, Elsevier Science, p. 383-420.

Madsen, J.H., Jr., 1976, Allosaurus fragilis: a revised osteology: Utah Geological and Mineralogical Survey, Bulletin 109, p. 3–163.

Marsh, A.D. and Rowe, T.B. 2020. A comprehensive anatomical and phylogenetic evaluation of *Dilophosaurus wetherilli* (Dinosauria, Theropoda) with descriptions of new specimens from the Kayenta Formation of northern Arizona. *Journal* of *Palaeontology*, **94**, 1–103.

Mounguengui, M., Lang, J. and Guiraud, M. 2008. Sedimentary dynamics and extensional structuring related to early Cretaceous rifting of Neocomian and Barremian deposits of the interior basin of Gabon. *Journal of African Earth Sciences*, **51**(5): 239-256. doi: 10.1016/j.jafrearsci.2008.01.

Mounguengui, M., Lang, J., Guiraud, M. and Jocktane, O. 2002. Sedimentary dynamics and structural geology of pre-rift deposits of the interior basin of Gabon. *Journal of African Earth Sciences,* **35**(2): 315-329. doi:10.1016/s0899-5362(02)00035-0

Melchor, R.N., Bedatou, E., De Valais, S. and Genise, J.F. 2006. Lithofacies distribution of invertebrate and vertebrate trace-fossil assemblages in an Early Mesozoic ephemeral fluvio-lacustrine system from Argentina: implications for the Scoyenia ichnofacies. *Palaeogeography, Palaeoclimatology, Palaeoecology*. **239**: 253–285.

Melchor, R.N., Bromley, R.G. and Bedatou, E. 2009. Spongeliomorpha in nonmarine settings: an ichnotaxonomic approach. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, **100**: 429–436.

Melo, B.G.V. and Carvalho, I.S. 2017. A Fauna da Formação Brejo Santo, Neojurássico da Bacia do Araripe, Brasil: Interpretações Paleoambientais. *Anuário do Instituto de Geociências UFRJ*, **40**, 62-74.

Mendes, D. Guzmán-González, J, Neumman, V.H.L.M. and Piovesan, E.K. 2020. Caracterização geológica e estratigráfica da região a norte de Inajá (PE), Bacia de Jatobá, nordeste do Brasil. *Revista de Geociências do Nordeste*, **6**, 32-44.

Méndez, A.H. 2014. The caudal vertebral series in abelisaurid dinosaurs. Acta Palaeontologica Polonica 59 (1): 99–107.

Naish, D., Martill, D.M. and Frey, E. 2004. Ecology, systematics and biogeographical relationships of dinosaurs, including a new theropod, from the Santana Formation (?Albian, Early Cretaceous) of Brazil. *Historical Biology*, **16**, 57–70.

Nesbitt, S.J.; Lager, M.C.; Schultz, C.L. 2019. The Anatomy of Asilisaurus kongwe, a Dinosauriform from the Lifua Member of the Manda Beds (~Middle Triassic) of Africa. The Anatoical record, Novas, F.E., Salgado, L., Suárez, M., Agnolín, F.L., Ezcurra, M.D., Chimento, N.R., De La Cruz, R., Isasi, M.P., Vargas, A.O. and Rubilar-Rogers, D. 2015. An enigmatic plant-eating theropod from the Late Jurassic period of Chile. *Nature,* **522**, 331–334.

Perea, D., Soto, M., Veroslavsky, G., Martínez, S. and Ubilla, M. 2009. A Late Jurassic fossil assemblage in Gondwana: biostratigraphy and correlations of the Tacuarembó Formation, Parana Basin, Uruguay. *Journal of South American Earth Sciences*, ***28***(2), 168-179. doi: 10.1016/j.jsames.2009.03.009

Perea, D., Ubilla, M., Rojas, A. and Goso, C.A. 2001. The West Gondwanan occurrence of the hybodontid shark and the Late Jurassic–Early Cretaceous age of the Tacuarembó Formation, Uruguay, 44(6), 1227–1235. doi:10.1111/1475-4983.00222

Pierini, C., Misuzaki, A.M., Pimentel, N., Faccini, U., F. and Scherer, C.M.S. 2010. Paleoweathering features in the Sergi Formation (Jurassic-Cretaceous), northeastern Brazil, and implications for hydrocarbon exploration. *Journal of South American Earth Sciences*, **29**, 412–426.

Pol, D. and Rauhut, O.W.M. 2012.A Middle Jurassic abelisaurid from Patagonia and the early diversifification of theropod dinosaurs. Proc. R. Soc. B, 279, 3170–3175.

Poropat, S.F. And J.P., Colin. 2012. Early Cretaceous ostracod biostratigraphy of eastern Brazil and western Africa: an overview. *Gondwana Research*, **22**, 772-798.

Pretto, F.A., Schultz, C.L., Langer, M.C. 2015. New dinosaur remains from the Late Triassic of southern Brazil (Candelária Sequence, Hyperodapedon Assemblage Zone). Alcheringa 39, 1–10.

Raath, M.A. and Mcintosh, J.S. 1987. Sauropod dinosaurs from the central Zambesi valley, Zimbabwe, and the age of the Kadzi formation. *South African Journal of Geology*, **90**, 107–119.

Rauhut, O.W.M. 2005. Osteology and relationships of a new theropod dinosaur from the middle Jurassic of Patagonia. *Palaeontology,* **48**, 87-110.

Rauhut, O.W.M. 2011. Theropod dinosaurs from the late Jurassic of Tendaguru (Tanzania). *Special Papers on Palaeontology*, **86**, 195–239.

Rauhut, O.W.M. and López-Arbarello, A. D. 2009. Considerations on the age of the Tiouaren Formation (Iullemmeden Basin, Niger, Africa): Implications for Gondwanan Mesozoic terrestrial vertebrate faunas. Palaeogeography, Palaeoclimatology, Palaeoecology 271, 259–267.

Rauhut, O.W.M. and Pol, D. 2017. A theropod dinosaur from the Late Jurassic Canãdón Calcáreo formation of Chubut, Patagonia, and the evolution of the theropod tarsus. *Ameghiniana*, **54**, 506–538.

Rauhut, O.W.M. and Pol, D. 2019. Probable basal allosauroid from the early Middle Jurassic Cañadón Asfalto Formation of Argentina highlights phylogenetic uncertainty in tetanuran theropod dinosaurs. Scientific Reports, 9:18826.

Rauhut, O.W.M. and Pol, D. 2021. New theropod remains from the Late Jurassic Canãdón Calcáreo formation of Chubut, Argentina. *Journal of South American Earth Sciences*, **111**, 103434.

Rees, J. A. N. and Underwood, C. J. 2008. Hybodont sharks of the English Bathonian and Callovian (middle Jurassic). *Palaeontology*, *51*(1), 117-147.

Rocha, D. E. G. A. and Leite, J. F. 2001. *Mapa geológico da Bacia do Jatobá, Geologia*. Recife, CPRM.

Rowe, T. and Gauthier, J. 1990. Ceratosauria. In: D.T. Weishampel, P. Dodson and H. Osmolska (eds.), *The Dinosauria*, University of California Press, Berkeley, pp. 151-16.

Sames, B. 2011. Early Cretaceous Theriosynoecum Branson 1936 in North America and Europe. Micropaleontology. 57. 291-344.

Sayão, J.M., Saraiva, A.Á.F., Brum, A.S., Bantim, R.A.M., Andrade, R.C.L.P., Xeng, X., Lima, F.J., Silva, H.P. and Kellner, A.W.A. 2020. The first theropod dinosaur (Coelurosauria, Theropoda) from the base of the Romualdo Formation (Albian), Araripe Basin, Northeast Brazil. *Scientific Reports*, **10**, 10892.

Schaller, H., 1969. Revisão Estratigráfica da Bacia de Sergipe/Alagoas. Boletim técnico da PETROBRAS 12 (1), 21e86.

Scherer, C.M.S., Lavina, E.L.C., Dias Filho, D.C., Oliveira, F.M., Bongiolo, D.E. and Aguiar, E.S. 2007. Stratigraphy and facies architecture of the fluvial–aeolian–lacustrine Sergi Formation (Upper Jurassic), Recôncavo Basin, Brazil. *Sedimentary Geology*, **194**: 169-193.

Scherer, C.M.S. and Lavina, E.L.C. 2005. Sedimentary cycles and facies architecture of fluvial-eolian strata of the Upper Jurassic Guará Formation, southern Brazil. *Sedimentology*, **52**, 1323-1341.

Silva, M. C., Barreto, A. M. F., Oliveira, E. V., Ruano, R. and Rocha, T. 2010. Vertebrados da Formação Aliança, Bacia de Jatobá, Nordeste do Brasil. In: VII Simpósio de Paleontologia de Vertebrados. Boletim de Resumos, p.59.

Silva, M.C., Carvalho, M., Barreto, A.M.F. and Carvalho, I. 2011. Paleoictiofauna da Formação Aliança (Jurássico Superior), Bacia de Jatobá, Nordeste do Brasil. 595–608. *In* Carvalho, I.S., Srivastava, N.K. and Lana, C.C. (eds). *Paleontologia: Cenários da Vida*. Interciência, p. 595-608.

Silva, D. R., Mizusaki, A. M. P., Milani, E. J. and Pimentel, M. 2012. Depositional ages of Paleozoic and Mesozoic prerift supersequences of the Recôncavo Basin in northeastern Brazil: A Rb/Sr radiometric study of sedimentary rocks. *Journal of South American Earth Sciences*, **37**, 13-24.

Silva, D.R.A.; Mizusaki, A.M.P.; Milani, E. and Tassinari, C.C. (2006). Idade deposicional da Formação Bananeiras (Bacia de Sergipe-Alagoas): uma aplicação do método radiométrico Rb-Sr em rochas sedimentares. *Boletim de Geociências da Petrobrás*, **14**:235-245.

Smith, N. D., P. J., Makovicky, W. R., Hammer, and Currie, P.J. 2007. Osteology of *Cryolophosaurus ellioti* (Dinosauria: Theropoda) from the Early Jurassic of Antarctica and implications for early theropod evolution, Zool. J. Linn. Soc. 151, 377-421.

Soto, M. and Perea, D. 2008. A ceratosaurid (dinosauria, Theropoda) from the Late Jurassic-Early Cretaceous of Uruguay. *Journal of Vertebrate Paleontology*, **28**, 439–444.

Soto, M., Toriño, P. and Perea, D. 2020a. A large sized megalosaurid (Theropoda, Tetanurae) from the late Jurassic of Uruguay and Tanzania. *Journal of South American Earth Sciences*, **98**, 102458.

Soto, M., Toriño, P. and Perea, D. 2020b. Ceratosaurus (Theropoda, Ceratosauria) teeth from the Tacuarembó Formation (late Jurassic, Uruguay). *Journal of South American Earth Sciences*, **103**, 102781.

Stumpf, S., Etches, S., Underwood C. J., Kriwet, J. 2021. Durnonovariaodus maiseyi gen. et sp. nov., a new hybodontiform shark-like chondrichthyan from the Upper Jurassic Kimmeridge Clay Formation of England. PeerJ 9:e11362.

Thomaz Filho, A., & Lima, V. Q. (1981). Dataçao radiométrica de rochas pelıcas pelo método Rb–Sr. *Boletim Petrobrás*, *24*, 109-119.

Tykosky, R.S. and T. Rowe. 2004. Ceratosauria. In The Dinosauria, second edition, ed. D.B. Weishampel, P. Dodson, and H. Osmo´lska, 47–70. Berkeley: University of California Press.

Yates, A. M. 2005. A new theropod dinosaur from the Early Jurassic of South Africa and its implications for the early evolution of theropods, Palaeont. Afr., 41, 105-122.

Viana, C.F and Van Hinte, J.E. 1966. Stratigraphic distribution of Ostracoda in the Bahia Supergroup (Brazil). In: West African micropaleontological colloquium, **2**, Ibadan, 1965, *Proceedings***…** Ibadan: 1965, Leiden, p. 240-257.

Viana, C. F., Gama Junior, E. G., Simões, I. A., Moura, J. A., Fonseca, J. R. and Alves, R.J. 1971. Revisão estratigráfica da Bacia do Recôncavo/Tucano. *Boletim Técnico da Petrobras*, **14**,157-192.

Figure 1 - Geographic and stratigraphic location of the studied specimen. A: lithological framework of the Jatobá basin and the location at the Macambira locality. B: Location of the Jatibá Basin in South America and Brazil. C: Geological map of the Jatobá basin; D: Regional geological map.

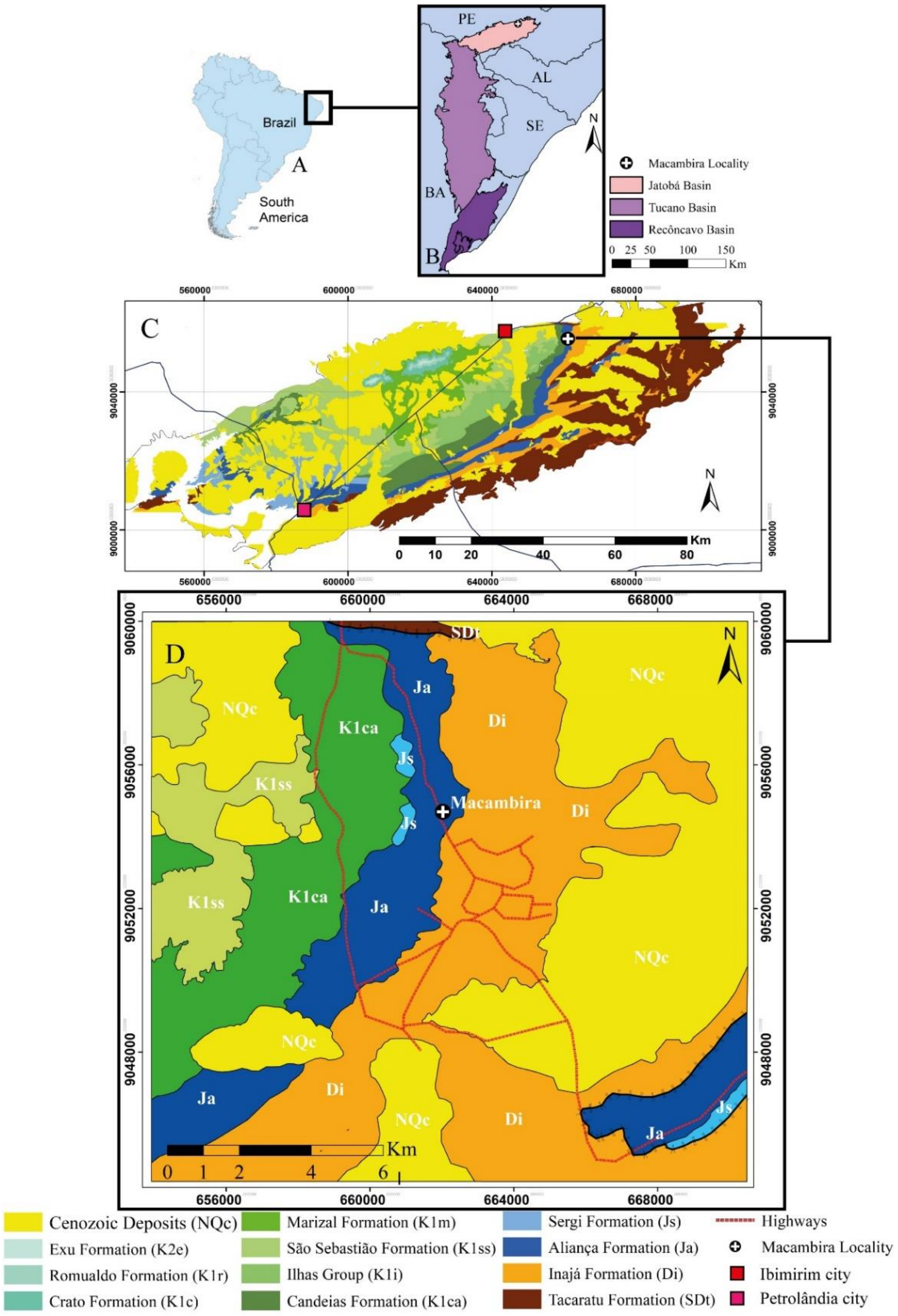


Figure 2 - Stratigraphic section of the Aliança Formation at the locality of Macambira, Jatobá basin, NE Brazil. A: Log section of studied outcrop; B: Detail of the upper layer of calcilutite; C: ripple marks in marbles; D: trace fossils of Spongeliomorpha; E: Detail of the laminated red mottled siltstones facies, where the vertebra was collected (Fl); F: general view of the dinosaur outcrop.

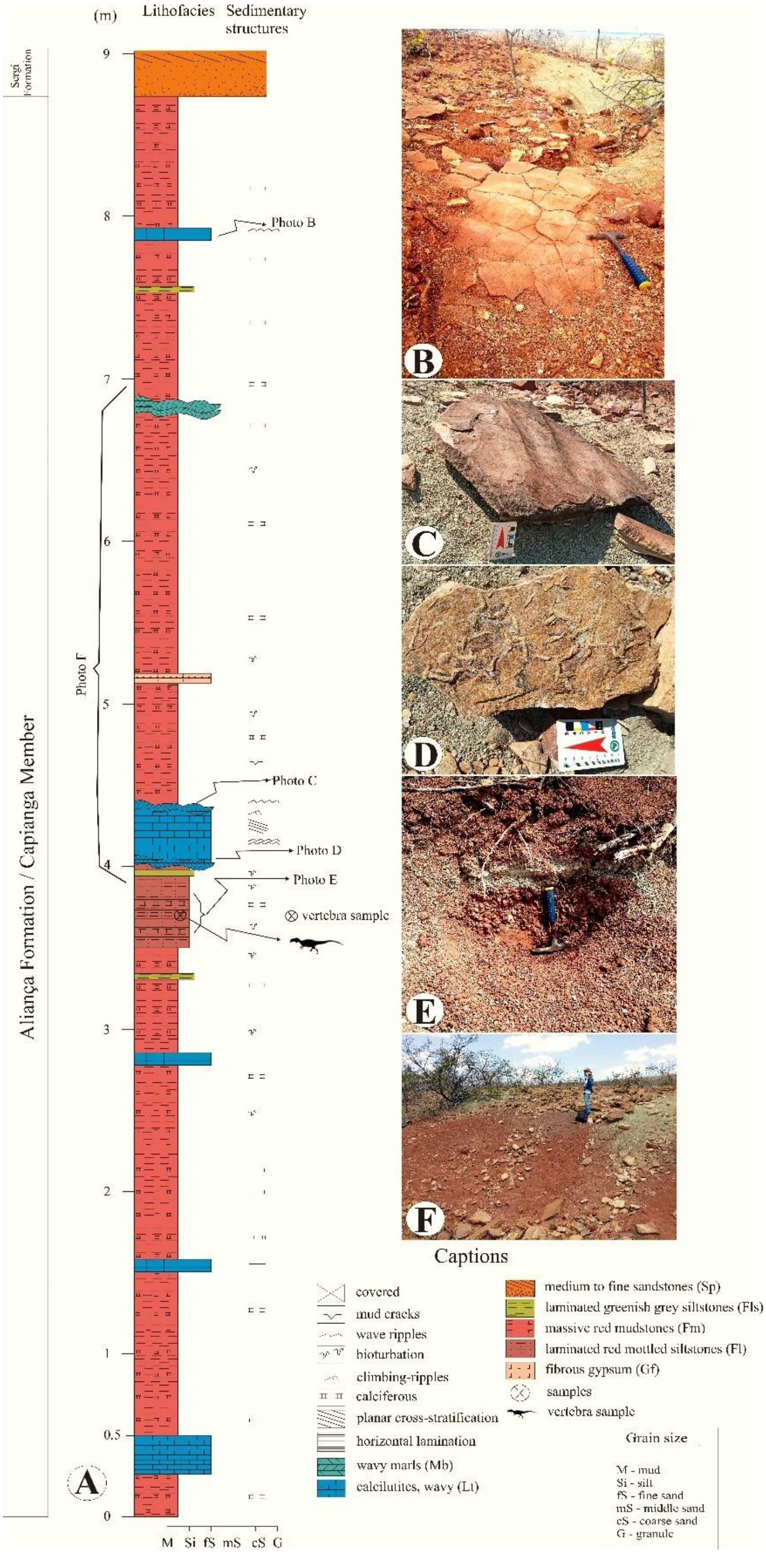


Figure 3 - Detail of the vertebra on the laminated red mottled siltstones. Scale bars represent: 20 mm.

Figure 4 - Incomplete middle caudal vertebra, DGEO-CTG-UFPE 8538. A: rigth lateral view; B: left lateral view; C: dorsal view; D: ventral view; E: anterior view; F: posterior view. Scale bars represent: 10mm.

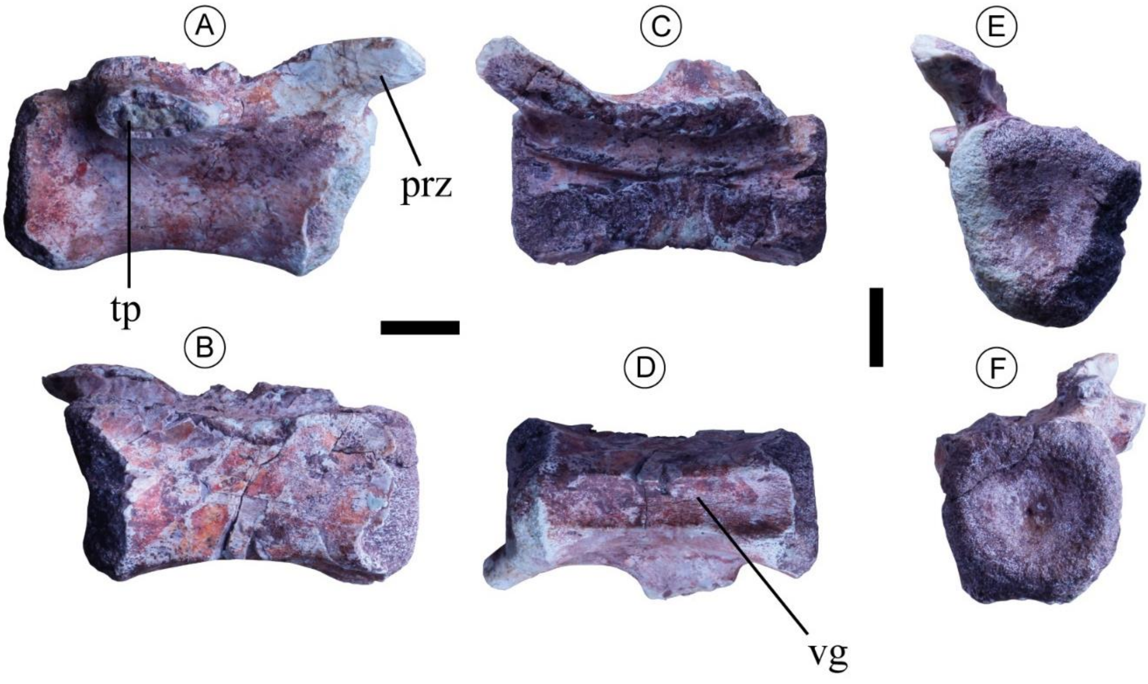


Figure 5 - Vertebrae of theropod dinosaurs. A: DGEO-CTG-UFPE 8538, inverted lateral view; B: *Dilophosaurus wetherilli* (Marsh and Rowe, 2020), lateral view; C: *Allosaurus fragilis* (redrawn from Madsen, 1976), lateral view; D: *lIokelesia aguadagrandensis* (redrawn from Coria and Salgado, 1998, lateral view; E: *Veterupristisaurus milneri* (Rauhut, 2011), lateral view; F: Carcharodontosauria indet. (Bandeira et al., 2021), lateral view; G: DGEO-CTG-UFPE 8538, ventral view; H: *Dilophosaurus wetherilli*, ventral view; I: Ceratosauria ("*Ceratosaurus* (?) *roechlingi*" (Rauhut, 2011), ventral view; J: *Veterupristisaurus milneri* (Rauhut, 2011), ventral view; K: *Condorraptor currumili* (Rauhut, 2005), ventral view; L: Carcharodontosauria indet. (Bandeira et al., 2021), lateral view. Not to scale.

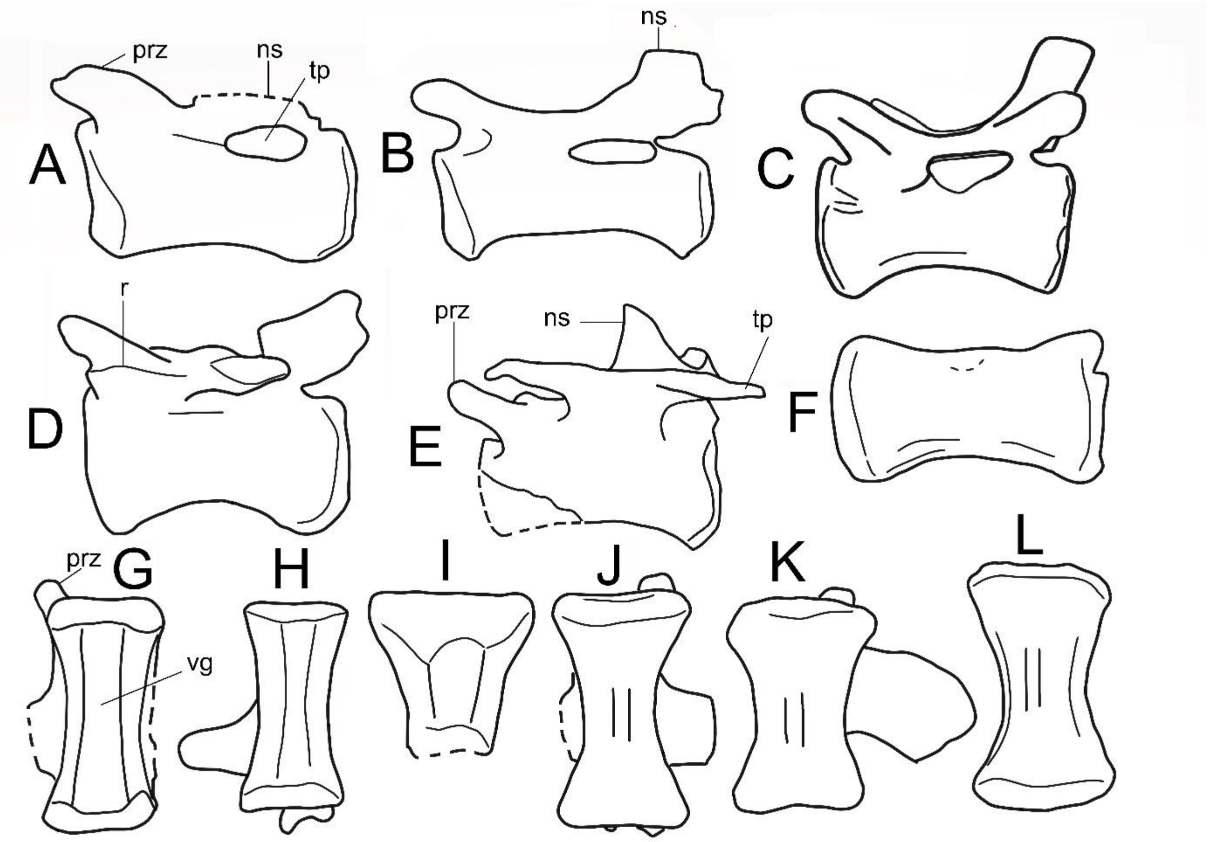


Figure 6 – (A) Early Jurassic theropod localities from the Pangea; (B) Middle and Late Jurassic theropod localities from the Gondwana.

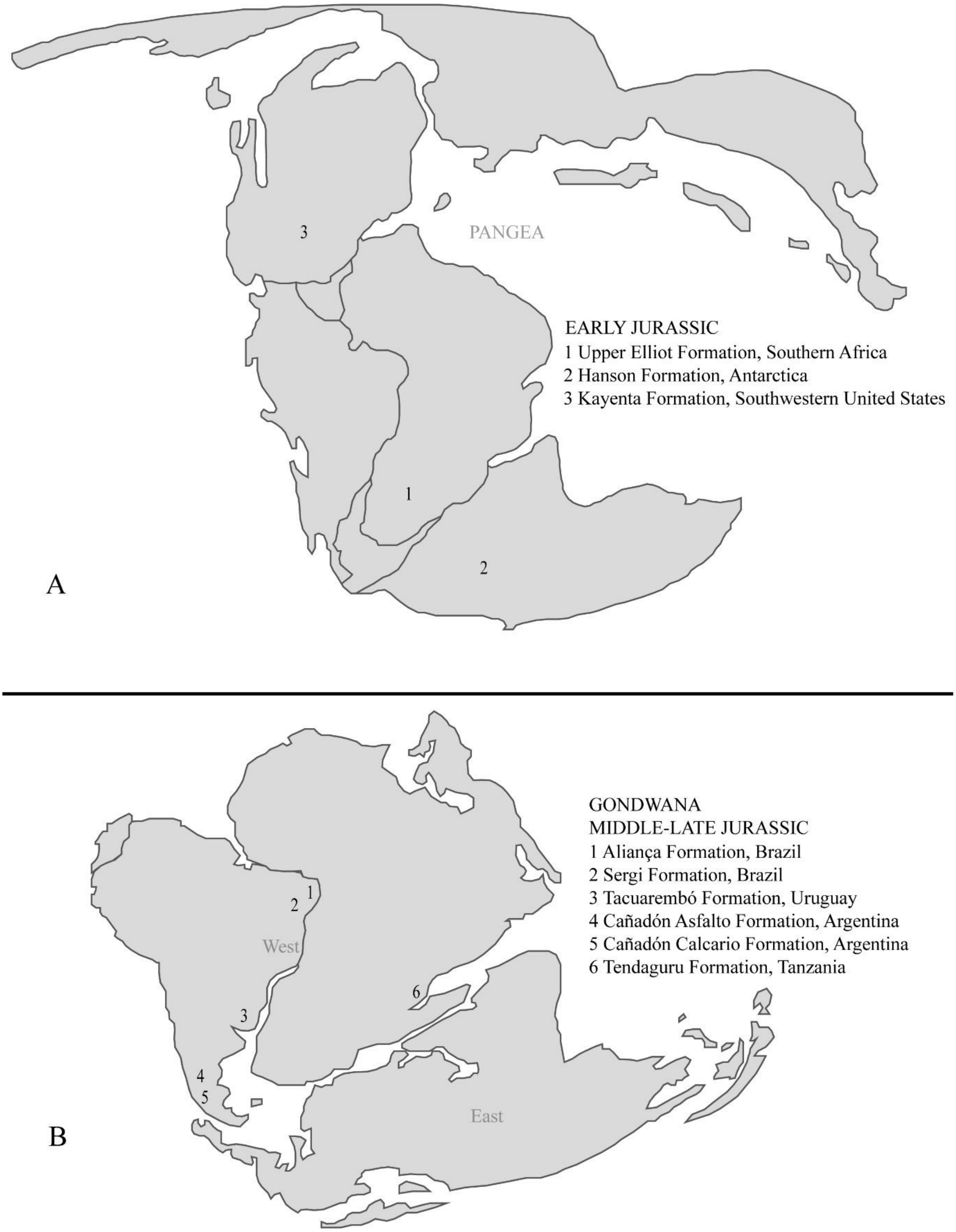
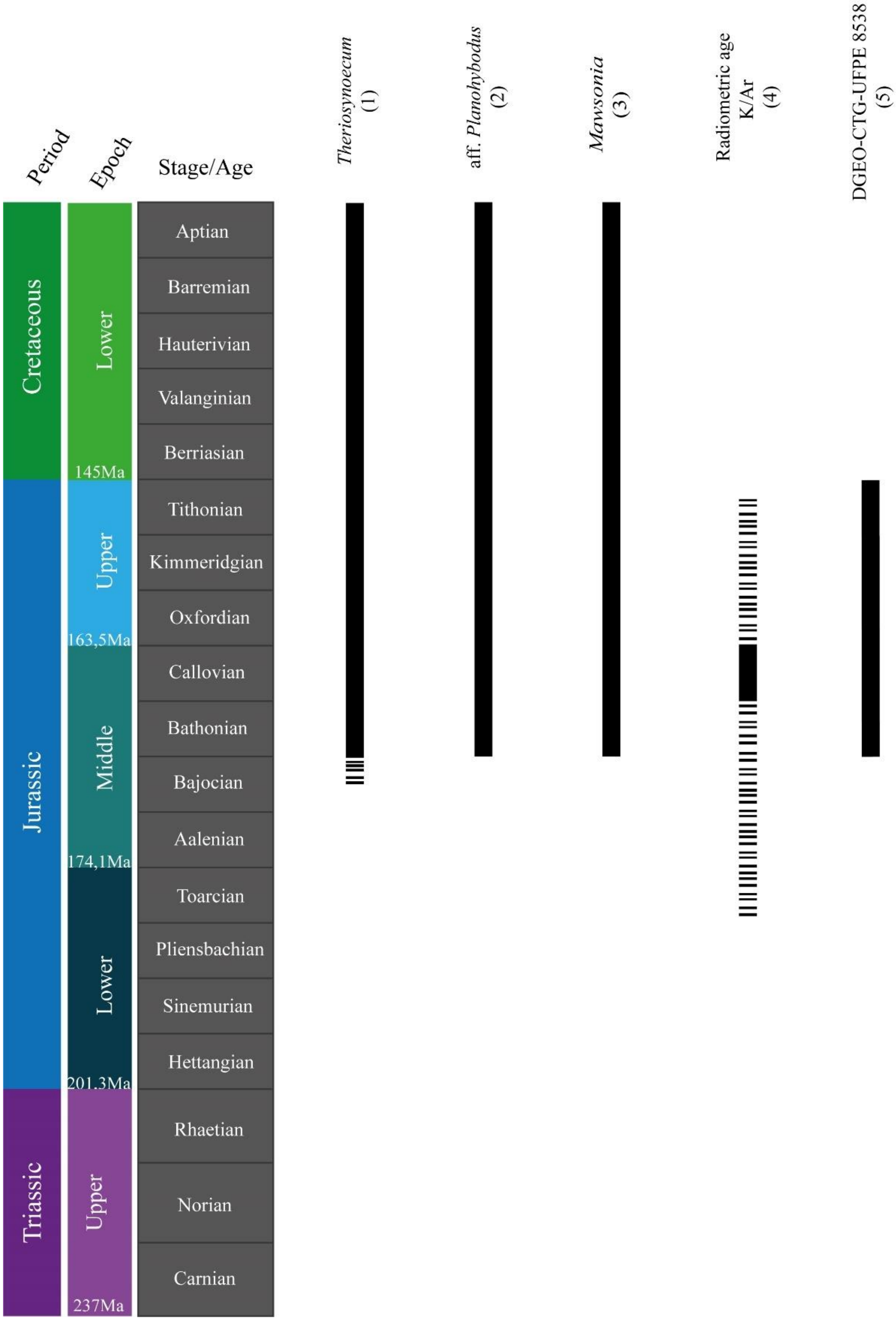


Figure 7 – Biochrons of the taxa identified to generic level in the Aliança Formation, and K/Ar age. References: (1) Ostracoda *Theriosynoecum* (Sames, 2011); (2) Hybodontiformes, aff. *Planohybodus* sp., (Rees and Underwood, 2008; Silva et al., 2011); (3) Actinistia, *Mawsonia*, Rauhut and López-Arbarello (2009); (4) Thomaz-Filho and Lima (1981); (5) DGEO-CTG-UFPE 8538.



5 Conclusões

1) Todos os fósseis de paleovertebrados coletados até o momento na Formação Aliança, aflorante na porção nordeste da Bacia de Jatobá, estão representados por elementos ósseos desarticulados, exibindo um intenso grau de retrabalhamento. resultante de uma maior duração do período de exposição subaérea pré-soterramento/*post-mortem*, onde podem ter atuado fatores tais como *trampling* (pisoteio) e possivelmente mastigação por carnivoria/necrofagia.
2) Duas classes tafonômicas foram identificadas, a classe **1** é formada por ossos isolados, semi completos (vértebras e ossos longos) a ossos raramente completos (e. g. osteodermos e escamas), com relativa alteração diagenética, enquanto a classe **2** é formada por um aglomerado de fósseis de tamanho pequeno, por vezes formando *bonebeds*, incluindo fragmentos ósseos indeterminados, dentes isolados, mandíbulas incompletas e escamas, exibindo alguns deles alteração diagenética.
3) A partir de dados litológicos e da cólera sistemática de fósseis da Formação Aliança na porção nordeste da Bacia do Jatobá, foram identificadas cinco litofácies para a Formação Aliança: **Fm** - Argilitos maciços, **Lt** – Calcilutitos, **Lc** – Calcarenitos, **Gf** – Gipsita fibrosa e **Scl** – Arenitos calcíferos.
4) Através da integração dos dados tafonômicos com as litofácies, identificou-se três tafofácies (**TF-A**, **TF-B** e **TF-C**). Estas tafofácies evidenciam que os eventos de retrabalhamento observados nos fósseis da Formação Aliança tiveram como causa a ação de correntes unidirecionais, de ondas de tempestades e do posterior rebaixamento do nível do lago em épocas mais quentes e secas, que remobilizaram os bioclastos. Desse modo, ciclos de baixa e alta pluviosidade se sucederam em um provável paleoclima quente no Gondwana Ocidental, evidenciado nos estratos por níveis carbonáticos exibindo estratificações cruzadas cavalgantes (*climbig-ripples*), argilitos maciços e níveis centimétricos de gipsita.
5) Foi descrito o primeiro registro de dinossauro terópode da Formação Aliança e segundo registro de dinossauro para a bacia. Sendo o registro, uma vertebra caudal atribuído ao grupo dos *Dilophosaurus*.
6) Esse registro está estreitamente relacionado a registros de Theropodas da Formação Tendaguru na Tanzânia, reforçando a idade neojurássica para os estratos da Formação Aliança. O registro de um terópode intimamente relacionado ao *Dilophosaurus wetherilli* na Formação Aliança também constitui o registro do primeiro fóssil não endêmico com um amplo poder de correlação paleobiogeográfica e bioestratigráfica no Gondwana Ocidental.

Referências

Anadón, P.; Cabrera, L.L.; Julia, R. & Marzo, M. 1991. Sequential arrangement and asymmetrical filling in the Miocene Rubielos de Mora Basin (northeast Spain). In: P. Anadon, L.L. Cabrera & K. Kelts (eds). Lacustrine Facies Analysis. International Association of Sedimentologists, Special Publication no. 13. Oxford: Blackwell. p. 257–75.

Assine, M.L. 2007. Bacia do Araripe. Boletim de Geociências da Petrobras, n. 2, p. 371-389. (Boletim 15).

Badam, G.L. & Ganjoo, R.K. 1986. Preliminary taphonomical studies of some Pleistocene fauna from the central Narmada Valley, Madhya Pradesh, India. Palaeogeography, palaeoclimatology, palaeoecology, **53**: 335-348. *doi: 10.1016/0031-0182(86)90067-2*

Bandeira, K.L.N., Brum, A.S., Pêgas, R.V., Souza, L.G., Pereira, P.V.L.G.C. and Pinheiro, A.E.P. 2021. The first Jurassic theropod from Sergi Formation, Jatobá Basin, Brazil. *Anais da Academia Brasileira de Ciências*, **93**, e20201557.

Behrensmeyer, A.K. 1978. Taphonomic and ecologic information from bone weathering. *Paleobiology*, 4(2): 150–162. *doi: 10.1017/S0094837300005820*

Bergqvist, L.P.; Almeida, E.B. & Araújo-Júnior, H.I. 2011. Tafonomia da assembleia fossilífera de mamíferos da “Fenda 1968”, Bacia de São José de Itaboraí, Estado do Rio de Janeiro, Brasil. *Revista Brasileira de Paleontologia*, **14**: 75-86. *doi:10.4072/rbp.2011.1.08*

Bittencourt, J.S. and Langer, M.C. 2011. Mesozoic dinosaurs from Brazil and their biogeographic implications. *Anais da Academia Brasileira de Ciências*, **83**, 23-60.

Bittencourt, J. S., Arcucci, A. B., Marsicano, C. A., & Langer, M. C. 2015. Osteology of the Middle Triassic archosaur Lewisuchus admixtus Romer (Chañares Formation, Argentina), its inclusivity, and relationships amongst early dinosauromorphs. *Journal of Systematic Palaeontology*, **13**(3): 189-219.

Bohacs, K.M.; Carroll, A.R.; Neal, P.J. & Mankiewicz, P.J. 2000. Lake-basin type, source potential, and hydrocarbon character: an integrated sequence-stratigraphicgeochemical framework. In: Gierlowski-Kordesh, E.H. & Kelts, K.R. (eds.). Lake basins Trough Space and Time; AAPG Studies in Geology, 46, p. 3-34.

Bohacs, K.M.; Carroll, A.R. & Neal, P.J. 2003. Lessons from lage lake systems-Thresholds, nonlinearity, and strange attractors. In: Chan, M.A. & Archer, A.W. (eds.). Extreme Depositional Environments: Mega end Members in Geological Time, vol. 370. Geological Society of America Special Papers, pp. 75-90.

Bordy, E.M. & Catuneanu, O. 2001. Sedimentology of the Upper Karoo fluvial strata in the Tuli Basin, South Africa. Journal of African Earth Sciences. **33**: 605-629. *doi: 10.1016/S0899-5362(01)00090-2*

Braun, O.P.G. 1966. Estratigrafia dos sedimentos da parte interior de região nordeste do Brasil (Bacias de Tucano-Jatobá, Mirandiba e Araripe). Rio de Janeiro, Departamento Nacional de Produção Mineral. Divisão de Geologia e Mineralogia. p. 75. (Boletim 236).

Buatois, L.A., and Mángano, M.G.,1995. The paleoenvironmental and paleoecological significance of the lacustrine *Mermia* ichnofacies: an archetypical subaqueous nonmarine trace fossil assemblage. *Ichnos,* **4**:151–161.

Buatois, L.A., and Mángano, M.G. 1998. Trace fossil analysis of lacustrine facies and basins. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **140**: 367-38.

Buatois, L.A., Mángano, M.G. Aceñolaza, F.G. 1996. Icnofaunas paleozoicas en sustratos firmes no marinos: evidencias del Pérmico de la cuenca Paganzo. *Ameghiniana*, **33**: 265–270.

Buffetaut, E., & Taquet, P. 1979. An early Cretaceous terrestrial crocodilian and the opening of the South Atlantic. *Nature*, ***280***(5722), 486-487.

Caixeta, J. M., Bueno, G. V., Magnavita, L. P., Feijó, F. J. 1994. Bacias do Recôncavo, Tucano e Jatobá. *Boletim de Geociências da Petrobrás*, **8**: 163–172.

Campos Neto, O.A.; Souza-Lima, W. & Cruz, F.E.G. 2007. Bacia de Sergipe-Alagoas. Boletim de Geociências da Petrobras, n. 2, p. 405-415. (Boletim 15).

Cardoso, R.N. 1966. Conchostráceos do Grupo Bahía: Brasil. Boletim do Instituto de Geologia, n. 2, p. 1-76. (Boletim 01).

Carrano, M. T. and Sampson, S. D. 2008. The phylogeny of Ceratosauria (Dinosauria: Theropoda). *Journal of Systematic Palaeontology*, **6**, 183–236.

Carvalho, A.R.A., Oliveira, G.R., Barreto, A.M.F. 2021. New Crocodylomorpha remains from the late jurassic Aliança Formation (Dom João stage), Jatobá Basin. Journal of South Americn Earth Sciences, **109**:103256.

Carvalho, I.S., 1993. Os conchostráceos fósseis das Bacias Interiores do Nordeste do Brasil. Programa de Pós-Graduação em Geologia, Universidade Federal do Rio de Janeiro Rio de Janeiro, Tese de Doutorado, 319p.

Carvalho, I.S., Leonardi, G., Rios-netto, A.M., Borghi, L., Freitas, A.P., Andrade, J.A., Freitas, F.I. 2021. Dinosaur trampling from the Aptian of Araripe Basin, NE Brazil, as tools for paleoenvironmental interpretation. *Cretaceous Research*, **117**: 1-14.

Cavinato, G.P.; Carusi, C.; Dall'asta, M.; Miccadei, E. & Piacentini, T. 2002. Sedimentary and tectonic Evolution of Plio–Pleistocene alluvial and lacustrine deposits of Fucino Basin (central Italy). *Sediemntary Geology*, **148**(1-2): 29-59. *doi: 10.1016/S0037-0738(01)00109-3*

Cesero, P. & Ponte, F.C. 1972. Análise comparativa da paleogeologia dos litorais atlânticos, brasileiro e africano. Boletim de Geociências da Petrobras, Rio de Janeiro, n. 2, p. 1-18. (Boletim 11).

Cladera, G.; Ruigomez, E.; Jaureguizar, E. O.; Bond, M. & López, G. 2004. Tafonomía de la Gran Hondonada (Formación Sarmiento, Edad-mamífero Mustersense, Eoceno Medio) Chubut, Argentina. *Ameghiniana*, **41**(3): 315-330.

Costa, I.P.; Bueno, G.V.; Milhomem, P.S.; Silva, H.S.L.E. & Kosin, M.D. 2007. Sub-bacia de Tucano Norte e Bacia de Jatobá. Boletim de Geociências da Petrobras, n. 2, p. 445-453. (Boletim 15).

Da rosa, A.A.S. & Garcia, A.J.V. 2000. Palaeobiogeographic aspects of Northeast Brazilian basins during the Berriasian before the break up of Gondwana. *Cretaceous Research*, **21**(2-3): 221-239. *doi: 10.1006/cres.2000.0209*

Davison, I. 1999. Tectonics and hydrocarbon distribution along the Brazilian South Atlantic margin. In: N.R. Cameron; R.H. Bate & V.S. Clure (eds.); The Oil and Gas habitats of the South Atlantic. London: Special Publications of Geological Society, 153 ed, p.133-151.

De Araujo Carvalho, A.R.; Oliveira, G.R. & Barreto, A.M.F. 2021. New Crocodylomorpha remains from the late jurassic Aliança Formation (Dom João stage), Jatobá Basin. *Journal of South American Earth Sciences*, **109**: 103256. *doi: 10.1016/j.jsames.2021.10325*

Delcourt, R. 2018. Ceratosaur palaeobiology: new insights on evolution and ecology of the southern rulers. *Scientific Reports*, **8**, 9730.

Derby, O.A. 1878. Contribuições para o estudo da geologia do Valle do rio São Francisco. Archivos do Museu Nacional, **4**: 119.

Derby, O.A. 1880. Geology of the rio São Francisco, Brazil. Ameriac Journal Science, **19**: 236.

Dodson, P. 1971. Sedimentology and taphonomy of the Oldman Formation (Campanian) Dinosaur Provincial Park, Alberta (Canada). *Palaeogeography, Palaeoclimatology, Palaeoecology,* **10**:21-74. *doi: 10.1016/0031-0182(71)90044-7*

Dunham, R.J. 1962. Classification of Carbonate Rocks According to Depositional Texture. In: Ham, W.E. (eds.). Classification of Carbonate Rocks, AAPG, Tulsa, p. 108-121.

Fambrini, G.L.; Neumann, V.H.M.L.; Lemos, D.R.; Araújo, J.T.; Lima-Filho, M.F. & Silva-Filho, W.F. 2010. Stratigraphy and sedimentology of the Rift Initiation to Rift Climax stages of the Araripe Basin, Northeastern Brazil: new considerations. In: INTERNATIONAL SEDIMENTOLOGICAL CONGRESS, 18, 2010. *Abstracts Volume*, Mendoza, Argentina. p. 333.

Fambrini, G.L.; Lemos, D.R.; Tesser Junior, S.; Araújo, J.T.; Silva-Filho, W.F.; Souza, B.Y.C. & Neumann, V.H.M.L. 2011. Estratigrafia, Arquitetura Deposicional e Faciologia da Formação Missão Velha (Neojurássico-Eocretáceo) na Área-Tipo, Bacia do Araripe, Nordeste do Brasil: Exemplo de Sedimentação de Estágio de Início de Rifte a Clímax de Rifte. *Geologia USP. Série Cientifica*, **11**(2): 55-87. *doi: 10.5327/Z1519-874X2011000200005*

Fambrini, G.L.; Neumann, V.H.M.L.; Barros, C.L.; Agostinho, S.M.O.; Galm, P.C. & Menezes-Filho, J.A.B. 2013. Análise estratigráfica da Formação Brejo Santo, Bacia do Araripe, Nordeste do Brasil: implicações paleogeográficas. *Geologia USP. Série Científica*, **13**(4): 3-28. *doi: 10.5327/Z1519-874X201300040001*

Fambrini, G.L.; Menezes Filho, J.A.B.; Jesuino, P.C.L.; Silvestre, D.C.; Lemos, D.R. & Neumann V.H.M.L. 2016. Caracterização dos sistemas deposicionais da Formação Barbalha, Bacia do Araripe, nordeste do Brasil. *Comunicações Geológicas*, **103**: 51-65.

Fambrini, G.L., Rocha, D.E.G.A., Oliveira, É.V., Jesuíno, P.S.L., Menezes-filho, J.A.B., Queiroz, R.G.B. and Neumann, V.H.L.M. 2019. Análise faciológica e deposicional dos depósitos flúvio-eólicos da Formação São Sebastião (Eocretáceo), região de Campos-Ibimirim, Bacia de Jatobá, PE, nordeste do Brasil. *Geociências,* **38**, 1-31.

Flessa, K.W.; Kowalewski, M. & Walker, S.E. 1992. Post-collection taphonomy: shell destruction and the Chevrolet. *Palaios,* **7**(5): 553-554. *doi:10.2307/3514853*

Fürsich, F.T. 1973. A revision of the trace fossils Spongeliomorpha, Ophiomorpha and Thalassinoides. *Neues Jahrbuch für Geologie und Paläontologie*, Monatshefte, 719–735.

Gasparini, Z. 1996. Biogeograpic Evolution of the South American Crocodilians; pp. 159-184 in G. Arratia (ed.), Contributions of Southern South America to Vertebrate Paleontology. Mtinchner Geowissenschaftliche Abhandlungen (A), **30**.

Goodwin, M.B.; Irmis, R.B.; Wilson, G.P.; Demar, D.G.; Melstrom, K.; Rasmussen, C.; Atnafu, B.; Alemu, T.; Alemayehu, M. & Chernet, S. G. 2019. The first confirmed sauropod dinosaur from Ethiopia discovered in the Upper Jurassic Mugher Mudstone, *Journal of African Earth Sciences*, **159**: 103571. *doi: 10.1016/j.jafrearsci.2019.103571*

Goodwin, M.B., Clemens, W.A., Hutchinson, J.H., Wood, C.B., Zavada, M.S., Kemp, A., Duffin, C.J. and Schaff, C.R. 1999. Mesozoic continental vertebrates with associated palynostratigraphic dates from the northwestern Ethiopian Plateau. *Journal of Vertebrate Paleontology*, **19**(4): 728-741

Gradzinsky, R., 1970. Sedimentation of dinosaur bearing Upper Cretaceous deposits of the Memegt Basin, Gobi Desert. *Palaeontologica Polonica*, **21**: 147-210.

Guzmán-González, J.; Fambrini, G.L.; Usma, C.C. & Oliveira, E.V. 2015a. Estratigrafia da Bacia de Jatobá: Estado da Arte. *Estudos Geológicos*, **25**: 53-76.

Guzmán-González, J. 2015b. Ostracodes e geoquímica das camadas carbonáticas da Formação Aliança da Bacia de Jatobá na localidade de Campos, Ibimirim-PE, Nordeste do Brasil. Programa de Pós-Graduação em Geociências, Universidade Federal de Pernambuco, Dissertação de Mestrado, 105 p.

Guzmán-González, J.; Piovesan, E.; Fambrini, G.L. & Oliveira, E.V. 2016. Non-marine Ostracoda from the Aliança Formation in the north-central portion of the Jatobá Basin, Northeastern Brazil. *Revista Brasileira de Paleontologia*. **19**: 15-24. *doi: 10.4072/rbp.2016.1.02*

Guzmán-González, J.; Sial, A.; Piovesan, E.; Oliveira, E.V. & Fambrini, G.L. 2020. Paleolimnological reconstruction of a marginal area of Jurassic Capianga Lake, Jatobá Basin, northeast Brazil. *Journal of Paleolimnology*, **63**: 113-128. *doi: 10.1007/s10933-019-00105-0*

Hendrickx, C., Hartman, S.A. and Mateus, O. 2015. An overview of non-avian Theropod discoveries and classification. *PalArch's Journal of Vertebrate Palaeontology*, **12**, 1-73.

Hill A. & Behrensmeyer, A.K. 1984. Disarticulation patterns of some modern East African mammals. *Paleobiology*, **10**(3): 366-376. *doi: 10.1017/S0094837300008332*

Holz, M. & Barberena, M.C. 1994. Taphonomy of the south Brazilian Triassic paleoherpetofauna: pattern of death, transport and burial. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **107**: 179-197. *doi: 10.1016/0031-0182(94)90170-8*

Holz M. & Simões, M.G. 2002. *Elementos fundamentais de tafonomia*, Ed. UFRGS, Porto Alegre.

Jones. J.; Frostick, L.E. & Aston, T.R. 2001. Braided stream and flood plain architecture: the Rio Vero Formation, Spanish Pyrenees. *Sedimentary Geology*, **139**(3-4): 229-260. d*oi: 10.1016/S0037-0738(00)00165-2*

Kuchle, J.; Scherer, C.M.D.S.; Born, C.C.; Alvarenga, R.D.S. & Adegas, F.A. 2011. Contribution to regional stratigraphic correlations of the Afro-Brazilian depression – The Dom João Stage (Brotas Group and equivalent units – Late Jurassic) in Northeastern Brazilian sedimentary basins. *Journal of South American Earth Sciences*, 31(4): 358-371. *doi: 10.1016/j.jsames.2011.02.007*

Leonardi, G. and Carvalho, I.S. 2007. Dinosaur ichnocoenosis from Sousa and Uiraúna-Brejo das Freiras basins, Northeast of Brazil. 355-369. *In* CARVALHO, I.S., CASSAB, R.C.T., SCHWANKE, C., CARVALHO, M.A., FERNANDES, A.C.S., RODRIGUES, M.A.C., CARVALHO, M.S.S., ARAI, M. and OLIVEIRA, M.E.Q. (eds) *Paleontologia: Cenários de Vida*. Rio de Janeiro, Interciência
Lyman, R.L. & Lyman, C. 1994. *Vertebrate taphonomy*. Cambridge University Press.

Magnavita, L.P. & Cupertino, J.A. 1987. Concepção atual sobre as bacias de Tucano e Jatobá, Nordeste do Brasil. Boletim de Geociências da Petrobras, n. 2, p. 119-134. (Boletim 1).

Magnavita, L.; Davison, I. & Kusznir, N. 1994. Rifting, erosion and uplift history of the Reconcavo-Tucano-Jatoba Rift, northeast Brazil. *Tectonics*, **13**: 367-388. *doi: 10.1029/93TC02941*

Magnavita, L.P.; Szatmari, P.; Cupertino, J.A.; Destro, N. & Roberts, D.G. 2012. The Recôncavo Basin. In: Roberts, D.G. & Bally, A.W (eds.). Regional Geology and Tectonics: Phanerozoic Rift Systems and Sedimentary Basins. Amsterdam: Elsevier Science, p. 383-420.

Malka, M.; Olsen, P.E. & Christie-Blick, N. 2003. Lacustrine facies typology in the Triassic-Jurassic rifts of eastern North America and Greenland compared to that of the Eocene Green River Formation of Wyoming. Northeastern Section. IN: 38th Annual Meeting (March 27-29, 2003). *The Geological Society of America (GSA), Session No*.

Marsh, A.D. and Rowe, T.B. 2020. A comprehensive anatomical and phylogenetic evaluation of *Dilophosaurus wetherilli* (Dinosauria, Theropoda) with descriptions of new specimens from the Kayenta Formation of northern Arizona. *Journal* of *Palaeontology*, **94**, 1–103.

Medeiros, M.A. 2010. Fossildiagênese. In: CARVALHO, Ismar de Souza (eds.). *Paleontologia: conceitos e métodos*, v. 1, 3 ed. Rio de Janeiro: Editora Interciência.

Miall, A.D. 1978. Lithofacies types and vertical profile models in braided-rivers deposits: a summary. In: Miall A.D. (eds.) *Fluvial Sedimentology*. Calgary, Canadian Society of Petroleum Geologists, p. 597-604.

Miall, A.D. 1996. *The geology of fluvial deposits: sedimentary facies, basin analysis and petroleum geology*. Berlin, Springer, 582 p.

Miall, A.D. *2006*. The *Geology* of Fluvial Deposists Sedimentary Facies, Analysis and Petroleum *Geology*. *Spring-Verlag*, New York, 582.

Miall, A.D. 2014. *Fluvial Depositional Systems*. Berlin, Springer (Geology), 316 p.

Melchor, R.N., Bedatou, E., De Valais, S., Genise, J.F. 2006. Lithofacies distribution of invertebrate and vertebrate trace-fossil assemblages in an Early Mesozoic ephemeral fluvio-lacustrine system from Argentina: implications for the Scoyenia ichnofacies. *Palaeogeography, Palaeoclimatology, Palaeoecology*. **239**: 253–285.

Melchor, R.N., Bromley, R.G, Bedatou, E. 2009. Spongeliomorpha in nonmarine settings: an ichnotaxonomic approach. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, **100**: 429–436.

Melo, B.G.V. and Carvalho, I.S. 2017. A Fauna da Formação Brejo Santo, Neojurássico da Bacia do Araripe, Brasil: Interpretações Paleoambientais. *Anuário do Instituto de Geociências UFRJ*, **40**, 62-74.

Mendes, D. Guzmán-González, J, Neumman, V.H.L.M. and Piovesan, E.K. 2020. Caracterização geológica e estratigráfica da região a norte de Inajá (PE), Bacia de Jatobá, nordeste do Brasil. *Revista de Geociências do Nordeste,* **6**, 32-44.

Mounguengui, M.M.; Lang, J. & Guiraud, M. 2008. Sedimentary dynamics and extensional structuring related to early Cretaceous rifting of Neocomian and Barremian deposits of the interior Basin of Gabon. *Journal of African Earth Sciences,* **51**: 239-256. *doi: 10.1016/j.jafrearsci.2008.01.008*

Naish, D., Martill, D.M. and Frey, E. 2004. Ecology, systematics and biogeographical relationships of dinosaurs, including a new theropod, from the Santana Formation (?Albian, Early Cretaceous) of Brazil. *Historical Biology*, **16**, 57–70.

Neumann, V.H.M.L.; Rocha, D.E.G.A.; Moraes, A.S.; Sial, A.N.; Castro, M.T.; Barbosa, J.A.; Fambrini, G.L. & Carvalho, R.R. 2010. Microfácies carbonáticas e comportamento isotópico de C e O nos calcários laminados aptianos lacustres da Serra Negra, Bacia do Jatobá, Nordeste do Brasil. *Estudos Geológicos*, **20**(1): 89-100.

Neumann, V.H.M.L.; Rocha, D.E.G.A.; Vortisch, W.; Gratzer, R.; Lima-Filho, M.; Barbosa, J.A. & FAMBRINI, G.L. 2013. Sedimentary Facies and Palaeoenvironmental Records of an Intracratonic Basin Lake: Aptian Lacustrine Crato Formation, Jatobá Basin, NE Brazil. In: AAPG ANNUAL CONVENTION AND EXHIBITION. Pittsburgh: AAPG, 2013, v. 50882.

Neumann, V.H.M.L. & Rocha, D.E.G.A. 2014. Stratigraphy of the Post-Rift Sequences of the Jatobá Basin, Northeastern Brazil. In: Rocha, R.; Pais, J.; Kullberg, J.C. & Finney, S. (eds.). *Strati 2013*. Cham: Springer International Publishing, p. 553- 557.

Neumann, V.H.; Miranda, T.S.D.; Figueiras, C.F.C. & Amaral, C.D.A. 2017. *Geologia e recursos minerais da Folha Poço da Cruz, SC.24- X-A-VI Estados de Pernambuco e de Alagoas*. CPRM-Serviço Geológico do Brasil, p. 1-62.

Novas, F.E., Salgado, L., Suárez, M., Agnolín, F.L., Ezcurra, M.D., Chimento, N.R., De La Cruz, R., Isasi, M.P., Vargas, A.O. and Rubilar-Rogers, D. 2015. An enigmatic planteating theropod from the Late Jurassic period of Chile. *Nature*, **522**, 331–334.

Peraro, A.A. 1995. Caracterização sísmica do tectonismo transcorrente na Bacia do Jatobá. In: 4TH INTERNATIONAL CONGRESS OF THE BRAZILIAN GEOPHYSICAL SOCIETY. Rio de Janeiro: *Anais*. p.1-3.

Perea, D., Soto, M., Veroslavsky, G., Martínez, S., & Ubilla, M. 2009. A Late Jurassic fossil assemblage in Gondwana: biostratigraphy and correlations of the Tacuarembó Formation, Parana Basin, Uruguay. *Journal of South American Earth Sciences*, ***28***(2), 168-179.

Pierini, C., Misuzaki, A.M., Pimentel, N., Faccini, U., F. and Scherer, C.M.S. 2010. Paleoweathering features in the Sergi Formation (Jurassic-Cretaceous), northeastern Brazil, and implications for hydrocarbon exploration. *Journal of South American Earth Sciences*, **29**, 412–426.

Ponte, F.C. & Asmus, H.E. 1978. Geological framework of the Brazilian continental margin. *Geologische Rundschau*, **67**: 201-235. *doi: 10.1007/BF01803262*

Ponte, F.C. 1992. Sistemas deposicionais na Bacia do Araripe, nordeste do Brasil. In: SIMPÓSIO SOBRE AS BACIAS CRETÁCICAS BRASILEIRAS, 2. Rio Claro: *Anais*. p. 81–84.

Ponte, F.C. 1994. Extensão Paleogeográfica da Bacia do Araipe no Mesocretáceo. In: SIMPÓSIO SOBRE O CRETÁCEO DO BRASIL, 3. Rio Claro: *Anais*. p.131-135.

Ponte, F.C. & Ponte Filho, F.C. 1996a. *Estrutura geológica e evolução tectônica da Bacia do Araripe*. Recife: DNPM, 4º e 10º Distritos Regionais, Delegacias do Ministério das Minas e Energia em Pernambuco e Ceará.

Ponte, F.C. & Ponte Filho, F.C. 1996b. Evolução tectônica e classificação da Bacia do Araripe. In: SIMPÓSIO SOBRE O CRETÁCEO DO BRASIL, 4. Águas de São Pedro: *Boletim UNESP*, p.123-133.

Poropat, S.F. and J.P., Colin. 2012. Early Cretaceous ostracod biostratigraphy of eastern Brazil and western Africa: an overview. *Gondwana Research*, **22**, 772-798.

Rocha, D.E.G.A. & Amaral, C.A. 2007. Caracterização Geologica e Geométrica dos Aquiferos (Meta B). In: Costa, W. D & Feitosa, F. A. C. *Hidrogeologia da Bacia Sedimentar do Jatobá: Sistema Aqüífero Tacaratu/Inajá.* Ministério de Minas e Energia - Ministério da Ciênica e Tecnologia.

Raath, M.A. and Mcintosh, J.S. 1987. Sauropod dinosaurs from the central Zambesi valley, Zimbabwe, and the age of the Kadzi formation. *South African Journal of Geology*, **90**, 107–119.

Rauhut, O.W.M. 2005. Osteology and relationships of a new theropod dinosaur from the middle Jurassic of Patagonia. *Palaeontology*, **48**, 87-110.

Rauhut, O.W.M. 2011. Theropod dinosaurs from the late Jurassic of Tendaguru (Tanzania). *Special Papers on Palaeontology*, **86**, 195–239.

Rauhut, O.W.M. and Pol, D. 2017. A theropod dinosaur from the Late Jurassic Canãdón Calcáreo formation of Chubut, Patagonia, and the evolution of the theropod tarsus. *Ameghiniana*, **54**, 506–538.

Rauhut, O.W.M. and Pol, D. 2021. New theropod remains from the Late Jurassic Canãdón Calcáreo formation of Chubut, Argentina. *Journal of South American Earth Sciences*, **111**, 103434.

Rocha, D. E. G. A. and J. F. Leite. 2001. *Mapa geológico da Bacia do Jatobá, Geologia*. Recife, CPRM.

Rocha, D.E.G.A. 2011. Caracterização do intervalo carbonático aptiano da Bacia do Jatobá, NE do Brasil. Programa de Pós-Graduação em Geociências, Universidade Federal de Pernambuco, Tese de Doutorado em Geociências - Centro de Tecnologia e Geociências, UFPE, 124 p.

Rowe, T. and Gauthier, J. 1990. Ceratosauria. In: D.T. Weishampel, P. Dodson and H. Osmolska (eds.), *The Dinosauria*, University of California Press, Berkeley, pp. 151-16

Sáez, A. & Cabrera, L. 2002. Sedimentological and palaeohydrological responses to tectonics and climate in a small, closed, lacustrine system: Oligocene As Pontes Basin (Spain). *Sedimentology*, **49**(5): 1073–1094. *doi: 10.1046/j.1365-3091.2002.00490.x*

Sales, A.M.F. 2005. Análise tafonômica das ocorrências fossilíferas de macroinvertebrados do Membro Romualdo (Albiano) da Formação Santana, Bacia do Araripe, NE do Brasil:

significado estratigráfico e paleoambiental. Programa de Pós-Graduação em Geociências, Tese de Doutorado. Universidade de São Paulo

Sayão, J.M., Saraiva, A.Á.F., Brum, A.S., Bantim, R.A.M., Andrade, R.C.L.P., Xeng, X., Lima, F.J., Silva, H.P. and Kellner, A.W.A. 2020. The first theropod dinosaur (Coelurosauria, Theropoda) from the base of the Romualdo Formation (Albian), Araripe Basin, Northeast Brazil. *Scientific Reports*, **10**, 10892.
Schaller, H. 1969. Revisão Estratigráfica da Bacia de Sergipe-Alagoas. *Boletim Técnico da Petrobrás*, **12**(1): 21 -86.

Scherer, C.M.S.; Jardim De Sá, E.F.; Córdoba, V.C.; Sousa, D.C.; Aquino, M.M. & Cardoso, F.M.C. 2014. Tectono-stratigraphic evolution of the Upper Jurassic– Neocomian rift succession, Araripe Basin, Northeast Brazil. *Journal of South American Earth Sciences*, **49**: 106-122. *doi: 10.1016/j.jsames.2013.10.007*

Seilacher, A. et al. 1976. Preservational history of compressed Jurassic ammonites from southern Germany. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **152**(3): 307-356.

Seilacher, A., 1991. Events and their signatures - an overview In: Einsele, G.; Ricken, W. & Seilacher, A. (eds.). *Cycles and Events in Stratigraphy*. Berlín, Springer-Verlag, p. 222-226.

Sereno, P. C., Wilson, J. A., & Conrad, J. L. 2004. New dinosaurs link southern landmasses in the Mid–Cretaceous. *Proceedings of the Royal Society of London.* Series B: Biological Sciences, **271**(1546), 1325-1330

Silva, M. C., Barreto, A. M. F., Oliveira, E. V., Ruano, R., Rocha, T. 2010. Vertebrados da Formação Aliança, Bacia de Jatobá, Nordeste do Brasil. In: VII Simpósio de Paleontologia de Vertebrados. Boletim de Resumos, p.59
Silva, M.C.; Carvalho, M.S.S. Barreto, A.M.F. & Carvalho, I.S.C. 2012. Paleoictiofauna da Formação Aliança (Jurássico Superior), Bacia de Jatobá, Nordeste do Brasil. In: Carvalho, I.S.; Srivastava, N.K.; Strohschoen, O. & Lana, C.C. (eds.). *Paleontologia: cenários de vida*, vol.4, Rio de Janeiro: Interciência, p. 595-608.

Simões, M.G. & Holz, M. 2000. Tafonomia: processos e ambientes de fossilização. In: CARVALHO, I.S. (ed.). *Paleontologia*. Rio de Janeiro: Ed. Interciência. p.19-46.

Sinibaldi, R.W. *2010. What Your Fossils Can Tell You*: *Vertebrate Morphology, Pathology, and Cultural Modification*. University Press of Florida.

Shipman, P. 1981. Applications of scanning electron microscopy to taphonomic problems. *Annals of the New York Academy of Sciences,* 276. *doi: 10.1002/j.2326-1951.1985.tb02780.x*

Smith, R.M.H., 1993, Vertebrate taphonomy of the Late Permian floodplain deposits in the southwestern Karoo Basin of South Africa. *Palaios*, **8**: 45-67 *doi: 10.2307/3515221*

Soares, M.B.A. 2003. Taphonomic model for the Mesosauridae assemblage of the Irati Formation (Paraná Basin, Brazil). *Geologica Acta: an international earth science journal*, **1**(4): 349-361.

Soto, M. and Perea, D. 2008. A ceratosaurid (dinosauria, Theropoda) from the Late Jurassic-Early Cretaceous of Uruguay. *Journal of Vertebrate Paleontology,* **28**, 439–444.

Soto, M., Toriño, P. and Perea, D. 2020a. A large sized megalosaurid (Theropoda, Tetanurae) from the late Jurassic of Uruguay and Tanzania. *Journal of South American Earth Sciences*, **98**, 102458.

Soto, M., Toriño, P. and Perea, D. 2020b. Ceratosaurus (Theropoda, Ceratosauria) teeth from the Tacuarembó Formation (late Jurassic, Uruguay). *Journal of South American Earth Sciences,* **103**, 102781.

Speyer, S.E. & Brett, C.E. 1988. Taphofacies models for epeiric sea environments: Middle Paleozoic examples. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **63**(1-3): 225-262. *doi: 10.1016/0031-0182(88)90098-3*

Talbot, M.R. & Allen, P.A. 1996. Lakes. In: H. G. Reading (eds.), *Sedimentary environments: processes, facies and stratigraphy*. New Jersey: Blackwell Science. p. 83-124.

Teisserenc, P. & Villemin, J. 1990. Sedimentary Basin of Gabon - Geology and oil Systems. In: Edwards, J.D. & Santogrossi, P.A. (eds.) *Divergent/Passive Margin Basins*. American Association of Petroleum Geologists, **48**: 117-199.

Tikosky, R.S., and T. Rowe. 2004. Ceratosauria. In The Dinosauria, second edition, ed. D.B. Weishampel, P. Dodson, and H. Osmo´lska, 47–70. Berkeley: University of California Press.

Uzunidis, A.; Pineda, A.; Jiménez-Manchón, S.; Xafis, A.; Ollivier, V. & Rivals, F. 2021. The impact of sediment abrasion on tooth microwear analysis: an experimental study. *Archaeological and Anthropological Sciences*, **13**(8): 1-17. *doi: 10.1007/s12520-021-01382-5*

Valença, L.M.M.; Neumann, V.H.M.L. & Mabesoone, J.M. 2003. An overview on CallovianCenomanian intracratonic basins of Northeast Brazil : Onshore stratrigraphic record of the opening of the southern Atlantic. *Geologica Acta*, 1(3): 261- 275.

Viana, C.F & Van Hinte, J.E. 1966. Stratigraphic distribution of Ostracoda in the Bahia Supergroup (Brazil). In: WEST AFRICAN MICROPALEONTOLOGICAL COLLOQUIUM, 2, Ibadan, 1965, *Proceedings*, Leiden, p. 240-256.

Viana, C.F.; Gama Junior, E.G.; Simões, I.A.; Moura, J.A.; Fonseca, J.R. & Alves, R.J. 1971. Revisão estratigráfica da Bacia Recôncavo/Tucano. Boletim Técnico da Petrobras, **14**(3- 4): 157-192. (Boletim 14).

Voorhies, M., 1966. *Taphonomy and population dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska*. University of Wyoming.